

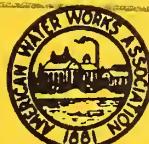
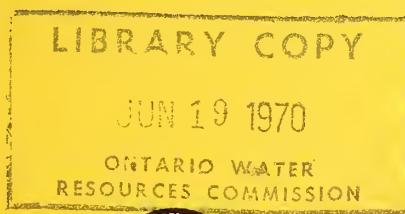


## THE THIRD WATER WORKS SEMINAR

on the topic of

MONITORING AND CONTROLLING THE  
WATER TREATMENT PROCESS

November 19, 1969



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The third water works seminar  
on the topic of monitoring and  
controlling the water treatment  
process.

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THE ONTARIO BRANCH - CANADIAN SECTION  
EDUCATION COMMITTEE - AWWA

and the

ONTARIO WATER RESOURCES COMMISSION

invite you to attend

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THE THIRD WATER WORKS SEMINAR

on the topic of

MONITORING AND CONTROLLING THE  
WATER TREATMENT PROCESS

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Seminar Chairman:

Paul Foley - OWRC

When: Wednesday, November 19, 1969 9:00 - 4:30 p.m.

Where: OWRC Laboratory - Lecture Hall  
Resources Rd., Rexdale (Toronto)  
(south-eastern corner of H'way 401  
and Islington Avenue)

Registration: \$5.00 (includes luncheon, coffee  
and doughnuts)

PROGRAMME :

9:00 Registration



Environment Ontario  
Laboratory Library  
125 Resources Rd.  
Etobicoke, Ontario M9P 3V6  
Canada

9:30 Word of Welcome ....

D. S. Caverly,  
General Manager - OWRC

9:40 Introductory Remarks ....

A. B. Redekopp,  
Chairman,  
Education Committee

D. B. Williams  
Brantford P.U.C.

/p.t.o.

PROGRAMME (continued)

9:50	Philosophy of Instrumentation	A. B. Patterson James F. MacLaren Ltd.
10:15	Coffee and Doughnuts	
10:45	Filter Control through Zeta Potential	J. W. Moffett Roberts Filter Mfg. Co. Pennsylvania
11:30	Filter Control through the Coagulant Control Centre	Hank Mueller, Neptune MicroFLOC Inc.
12:15	Turbidity Monitoring	C. J. Weidner, Hach Chemical Co.
1:00	Lunch	
2:15	Operator Experience of Filter Control by Use of Suspended Solids Determina- tion with Millipore Filters	R. E. Hansen, Mt. Clemens, Michigan
2:45	Recording and Controlling the Chlorine Residual	R. J. Baker, Wallace & Tiernan
3:45	Open Discussion and Closing Remarks by Chairman	
4:30	Seminar closes	

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THE ONTARIO BRANCH - CANADIAN SECTION - AWWA  
EDUCATION COMMITTEE

A. B. Redekopp	- Chairman	P. Foley	- Toronto
R. Tredgett	- Toronto	T. Gagen	- London
D. B. Williams	- Brantford	R. Pequegnat	- Kitchener
E. Loft	- Windsor	S. Bonk	- Ottawa
R. Reynolds	- Lindsay	R. Peacock	- Oshawa

## INTRODUCTORY REMARKS

D. B. Williams  
Water Works Chemist  
Brantford Public Utilities Commission

In view of our programme dealing largely with those facets of the water treatment process that can influence the public health, I would like to attempt to set the stage for such an excellent programme by a brief review of some water works history.

For simplicity I will not attempt to encompass all water works history in all parts of the world, but will confine my remarks to the attempt to produce safer waters in Western Europe and America.

For a long time after the dark ages it can be said that the water supplies in the centres of population in Europe ran the gamut from excellent, down through good, fair and poor to downright lethal.

Fire was always a problem in cities built mainly of wood, so quite early we find pipes being laid in the streets. In London and Paris the normal procedure was to pump raw river water into these pipes. With supplies from wells being inadequate the citizens would naturally use this raw river water for purposes other than putting out fires. If the river was in quiescent stage you received a relatively clear germ-laden water. If the river was in flood stage you received a germ-laden muddy water.

Unsuccessful attempts were made to filter the raw river water, scrap wool being used in London and sea sponges in Paris.

Finally, engineers at the University of Aberdeen designed and built the first slow sand filters for London. The use of slow sand filters became widespread, the sole intent of filtration being to make the water clear and attractive.

Of importance to us was that the increasing use of water filtration roughly coincided with the new age of bacteriology.

Hamburg, in 1892, still not having filters and drawing from the polluted Elbe suffered some 18,000 cases of CHOLERA, 8,000 of which died, whereas Altoona, downstream, but employing slow sand filters was not able to record a single case. Thus, this new breed of scientists, the bacteriologists, were able to show that filtered water was safer.

THEN and THERE, the process of water filtration became the water works operator's primary line of defence to protect his public against the ravages of these newly discovered disease organisms.

While slow sand filters were good in respect to making water safer they had a number of drawbacks, only two of which we will mention - the large maintenance effort and the large square footage required to give a unit volume of water.

To remove these objections workers in America developed the rapid sand filter, with which we are all quite familiar.

Initially, some of these filters were good whereas others, no doubt due to the raw water supply being more polluted, did pass bacteria. There is a long involved history of the early attempts to improve rapid sand filtration by changing the depth and type of sand, by placing settling tanks in advance of the filters and by employing some form of chemical coagulation prior to settling and filtration.

Despite the value of these new rapid sand filters and all the early developmental work involved with them, the cold hard truth was that they did not always remove harmful bacteria from the water and, therefore, another primary line of defence was required.

Just at the beginning of this century chlorination entered the water treatment field. Right from the start it proved of such great value that it became in the minds of many water works personnel the one and only primary line of defence to protect the public against waterborne disease.

With this new shining knight in armor, chlorination as the one and only line of defence, what happened in the minds of these same people in regard to the filters? Were the filters still considered a primary line of defence - No! To many of them the filters were relegated to the job of merely taking the mud out of the water to make it look pretty, to make it clear and attractive.

To me this has long been erroneous thinking. Even though I am often classed as a chlorination "bug", and look upon chlorination as a good primary line of defence, I still consider filtration with its attendant procedures of coagulation, flocculation and settling to also be a good primary line of defence. Separately they are both good, together they provide excellence.

I consider filters excellent for removing those things that chlorination cannot always attack - for example, bacteria and viruses embedded in particles of sewage. I consider chlorination excellent for killing and/or inactivating those things that filters do not always remove - for example, unattached bacteria and viruses.

These contentions are borne out by a research study by H.E. Hudson of Hazen and Sawyer, in which epidemiological evidence in the populations served by some 11 water treatment plants situated on one river in the U.S.A. clearly showed:

- (1) that in two water treatment plants having identical chlorination programmes, the plant sending out the lower finished water turbidity had the lower incidence of waterborne bacterial and viral disease among its customers.
- (2) that in two water treatment plants sending out identical levels of turbidity in the finished water, the plant having the more advanced chlorination programme had the lower incidence of bacterial and viral disease in its population served.
- (3) particularly - in one plant where turbidity removal was better than all the others, and where the chlorination programme was better than all the others, this plant outshone all the others by having the lowest incidence of waterborne bacterial and viral diseases in population served.

Therefore, to safeguard our public, we need the very best in clarification and disinfection by chlorine, and we particularly require that at all times these two primary lines of defence be operating in a proper manner, and that is what this very important programme is all about!!!

## PHILOSOPHY OF INSTRUMENTATION

A. B. Patterson, Director  
James F. MacLaren Limited

Instrumentation and control play a vital part in the successful operation of a modern water treatment plant. This aspect of the plant should receive, therefore, as much consideration in the planning and design stage as any of the other various steps in the process.

For this reason, it is indeed timely and much to the credit of the Education Committee of the Ontario Branch Canadian Section AWWA, that they have seen fit to sponsor and promote this Seminar, the third in a continuing series. I would like, therefore, to add my words of appreciation to this Committee, the hard-working Chairman, Mr. A.B. Redekopp, and the members of his Committee. You gentlemen are serving our industry well and deserve encouragement and support from all segments.

Considerable progress in the development and application of instruments for the control of water treatment plant processes has taken place and the state of the art is continuing to advance at an almost frightening rate. At the same time, efforts in design and application techniques are being made to improve reliability, facilitate maintenance and provide more accurate control.

Faced, as we are, with the whole host of new and improved equipment and control devices, I find it necessary at this point to stop, to pause and to reflect on the purpose or objectives of instrumentation and control in a water plant. I believe they are three in number:

- 1) To produce a better product at lower cost
- 2) To control certain key functions in order to maintain a balanced throughput
- 3) To provide data listing of all key functions so that operating personnel and management can study and analyze results, recognize trends and take appropriate action

Instrumentation and control, when properly applied and installed in accordance with manufacturers standards, and most important of all, properly and regularly maintained, will accomplish these objectives.

It follows, therefore, that instrumentation applied haphazardly, in the wrong application, poorly maintained, can cause operational problems that result in additional expense and poor quality control.

It is incumbent upon the design engineer, therefore, to determine the extent of information required to operate the plant. There are many factors to consider - size of plant - difficulty of treatment of water - number of control points - location of various steps - number and quality of operating personnel available - operator philosophy - possible operating problems - cost - and time of response.

I will not attempt to review the types of systems available. Let me simply say that I am old enough to have cut my teeth in this business on a mechanical system. You know the story - locally mounted at the point of measurement - floats that water log-pulleys that bind and seize - links that wear - gears that strip - cables that stretch and clocks that wind with a key.

The introduction and acceptance of the pneumatic, electric, electro pneumatic, hydro pneumatic and electro hydraulic modes of operation has freed us from the "cables and links" era and made possible a whole new approach to control systems.

#### CENTRALIZED CONTROL

With the ability to collect data and to control key process or treatment variables, a trend has accelerated over the last ten years towards master centralized control panels, graphic displays and completely automated closed loop systems.

This concept has had increasing acceptance by design engineers. I am told that industry has accepted this concept completely. Advances are continuing. Digital displays or read out of material expressed in discreet digital form such as coded punched paper tape, magnetic tape or typewritten log sheets is just around the corner, or since I have not seen the morning paper, I had best say have arrived. It remains then, only necessary to feed this information into a programmed computer to obtain optimum operating procedures. This is now being done in the more sophisticate systems.

Where then, in the face of the information explosion do we as owners, operators, or designers stand?

No one can be passive or resistant to change forever. We have to "swing" or we will be left behind. Water works people, generally speaking, are known to be resistant to change. They have to be. So much of what they do is completely open to the public. A short interruption to a commodity as vital as a water supply is immediately noticed by hundreds of citizens and telephones in offices of public officials ring.

What will happen here to-day is absolutely vital to our industry. Suppliers and users have an obligation to the public. The obligation is to produce the best for the least. Today you will hear of the latest developments in the monitoring and control field. Listen carefully, ask searching questions, but above all, ask yourself, sincerely,

- 1) Will these innovations produce a better product at a lower cost?
- 2) Can I do a better job of controlling my throughput?
- 3) Do I really need this mass of detail and data?

The decision process commences with a data and facts finding exercise. This is the purpose of today's seminar.

If you are not ready to adopt, then consider adapt as your instrumentation philosophy.

FILTER PLANT CONTROL  
THROUGH ZETA POTENTIAL

by

J. Wm. Moffett  
Chemical Engineer  
Roberts Filter Manufacturing Co.  
DARBY, PA. 19023

INTRODUCTION

The minimum function of a water treatment plant is to produce a safe, potable water in quantities that meet increasing demands. The requisites of society, however, are becoming more rigorous. No longer are they satisfied with a minimum quality water but are demanding one that is appealing to the aesthetic senses in that it is clean, colorless and pleasant to the taste. The trend for higher quality requirements will undoubtedly continue to increase. The public is becoming more sophisticated toward public health from mass communications media reports on pollution, the physiological effects of certain pollutants and the advances in human disease etiology as related to viruses and new, more virulent strains of bacteria.

Unfortunately, the necessity for increased quantity has been allowed to overshadow quality at some locations. This condition should not be allowed to persist. The technology, the techniques, and the "know-how" are available to produce high quality finished waters at high demand rates. Process engineering, process monitoring and operating techniques are the "keys" to successful plant operation and effluent quality.

## PROCESS ENGINEERING

The objective of process engineering is to first devise an economical chemical treatment scheme that, with suitable modifications, can successfully coagulate the raw water at all times. Then to optimize the physical parameters of the unit operations in the plant so that the desired chemical and physical reactions are carried out efficiently.

The importance of process engineering is just now becoming recognized. This greater emphasis is due to the necessity of using lower grade raw water supplies and to the availability of plant equipment to define product quality. Heartening though this trend is, there are still frequent cases where neither time nor funds are available for adequate process studies. Too often, plant designs are based on a laboratory chemical and physical analysis of the water supply or on past operating history of other plants, even though these plants lack equipment to critically evaluate the process or the product quality.

Chemical substances that interfere with the water treatment process are usually pollutants and are present in varieties and in concentrations that make chemical analysis of little value. These pollutants are generally industrial or natural occurring wastes. Accepted water treatment methods are available to handle simpler ones such as Fe, Mn,  $H_2S$ , etc. Complex pollutants such as Industrial wastes and wetting agents, insecticides and herbicides, or waste products of animal and plant life present problems for which there are no standard treatment methods. In addition to being of

of highly sophisticated chemical structure, pollutants can appear in many forms in the raw water. They may be present in solution or as colloids or as adsorbates on the surface of other colloids. Further, they may exhibit hydrophyllic, amphoteric or chelating properties. Also, pollutants are rarely ever in constant, absolute concentration or in constant relative concentrations to each other.

In devising a chemical treatment scheme for a contaminated raw water, rarely does the process engineer have the opportunity or the means of identifying the pollutants or their individual effects. Rather, he must use test techniques that evaluate the overall effect of the pollutants on the coagulation process. To this end, the jar test is still the most valuable tool. Any resemblance, however, between the old "eyeball" jar test and modern jar testing techniques is coincidental.

The jar test must be conducted under controlled conditions so that thermodynamic driving forces for all chemical reactions are optimized within the limits that will prevail in the operating plant. If this concept is followed, both in jar testing and in process design of the plant, the results from the jar test should agree with plant operation within  $\pm$  1ppm of alum and to within  $\pm$  0.1pH unit of the optimum pH.

Process engineering data and calculations should include:

- 1) Location and dosage of each chemical feed.
- 2) The reaction conditions, i.e., pH, temperature, degree of mixing, etc.

- 3) The settling, the surface and the strength characteristics of the floc.
- 4) Filter media design.
- 5) Prediction of the plant effluent quality.
- 6) A chemical treatment cost analysis for each process evaluated.

Increasing pollution of existing water supplies combined with increasing water demands may make process changes necessary in existing plants. In those instances that the jar tests indicate major process revisions, pilot plant or plant scale studies should be initiated. When plant trial runs are feasible, they will supply more information than will the pilot plant work.

#### MONITORING COAGULATION

A number of methods have been suggested for monitoring the coagulation step. My preference is for the process which combines monitoring the pH of coagulant chemical reactions and zeta potential of the floc formed. The reasons for this preference are explained by the chemistry of coagulant chemicals and the fundamental definition of zeta potential in colloidal chemistry.

#### COAGULANT CHEMISTRY

All metal cations are hydrated in water solution. These aquo metal ions are proton donors (acidic) and form colloidal, hydroxo, metal polymeric ions, as intermediates in the formation of metal hydroxide precipitates. It is the intermediate soluble, hydroxo, metal ions that coagulate or destabilize turbidity colloids in water.

It is believed that the effective hydrolysis products for coagulation are of the types:  $[Al_6(OH)_{18}]^{+3}$ ,  $[Al_7(OH)_{17}]^{+4}$   $[Al_8(OH)_{20}]^{+4}$  or  $[Al_{13}(OH)_{34}]^{+5}$ . Chemical conditions are such that a mixture of these components is formed. In keeping with the Schulze-Hardy rule, the most effective coagulant will be the mixture with the highest average positive valence. Which hydroxo metal ion will predominate is a function of pH.

The hydroxide ion is only one of the ligands which can enter into the chemical structure of the coagulant ion. Other basic ions such as carboxyl, phosphate, sulfate, chloride, etc. may take part in the complex ion formation. The chemical structure of the various hydrolysis products determine their electrical charge and the chemical structure is determined by the coagulant, the solution composition and the pH of reaction. This means that for any given coagulant and water supply there will be an optimum pH at which the most effective use is made of the coagulant. Fig. I illustrates this point in showing that the most effective use of the coagulant chemical occurs at one pH - the optimum. At pH's above or below the optimum flocculation, settling and filtration will be less efficient.

#### ZETA POTENTIAL

Zeta potential is the repulsive force between colloids and results from the electrical double layer surrounding each turbidity particle. Coagulation in water treatment is defined as the destabilization produced by compression of the electrical double layers

surrounding the turbidity particles. Reworded, coagulation is the reduction of zeta potential by the coagulant chemicals. Accordingly, zeta potential monitoring of coagulation is based on the definition of coagulation and is a direct measure of the efficiency of coagulation.

For example, Figure II shows a typical curve for turbidity in the filter effluent versus coagulant dosage at constant pH. The highest quality effluent will be produced between points C and E but is the general practice to operate between points C & D to conserve coagulant chemicals. However, each point on this curve has a unique value of zeta potential and the water plant operator can control his coagulation to produce any desired quality finished water.

Figure II can be used to illustrate the efficiency of the pilot column technique for controlling coagulation. It is basic that for the pilot column to function there must be either uncoagulated turbidity or under-coagulated floc appearing in the effluent so that a readable output is obtained on the turbidimeter. Further, there must be a readable change in pilot column effluent turbidity with a minimum change in coagulant chemical feed. This means that the pilot column cannot be operated between points C and E to produce the highest quality water. The pilot column must be operated between the points A and C with coagulants, then filter aid feed instituted to achieve quality.

Pilot column results are not directly applicable to plant operations because of differences in the surface chemistry of the

two flocs due to aging and other effects. An empirical relationship must be used to apply pilot column results to the operating plant.

Both the optimum pH and the optimum zeta potential can be monitored by a Zeta Meter.\* This coagulation monitoring technique has a number of advantages.

- 1) Plant control is based on floc in the plant--flash mix effluent--and no empirical relationships are required.
- 2) The method is fast and positive.
- 3) The techniques are within the range of the average operator's skills.
- 4) The method not only informs the operator when to correct chemical dosages, but it tells him how to do it; that is, whether to increase or decrease dosage.
- 5) The method optimizes pH as well as coagulant dosages.
- 6) It is the only method that will produce the highest quality effluent consistently.

#### FILTER AID

Non-ionic polyelectrolytes can be fed to the filter influent and used as filter aids to increase the strength of floc bonds when the floc is absorbed on filter media. The exact mechanism by which polyelectrolytes bridge between particles is not known but it is believed to be by chemical reaction.

When used in this manner, polyelectrolytes will promote the production of high quality effluents even though the floc is under

\*Zeta Meter, a product of Zeta Meter, Inc., New York, New York

coagulated in the range of -5 to -13 zeta potential. If the floc is properly coagulated in the range of 0 to 5 zeta potential at the optimum pH, polyelectrolytes will not improve the filtered water quality. Accordingly, it is recommended that filter aids only be used when the coagulation is not optimum because of operator or equipment failure. They can be looked upon as insurance to assure production of high quality effluents at all times.

It is very difficult to determine the correct feed rate for polyelectrolytes. Underfeeding will result in early break through due to weak floc. Overfeeding will shorten the runs by rapidly increasing the rate of head loss. The best solution is to properly coagulate at all times and not depend upon a filter aid for the production of high quality water.

#### PROCESS MONITORING

Instrumentation is available to monitor significant process variables and product quality parameters. The importance of this equipment in maintaining plant efficiency and assuring a constant, high quality finished water is difficult to overemphasize. No longer must operators depend upon "seat-of-the pants" methods. Rigorous and definitive numerical values can be determined that will indicate the effectiveness of coagulation and the efficiency of the water treatment process throughout the plant.

In addition to monitoring of water levels, rate of flows, and loss of heads and chlorine residuals, it is suggested that the following parameters be measured at the indicated locations and possibly recorded for record purposes. [Figure III].

The data on the raw water will inform the operator of a change in the chemical or physical constituents in his supply. A major change in one or more of the variables will alert him to the possible necessity for revision of his chemical treatment. History is the best teacher. Experience will soon show the operator the significance of changes in the raw water variables as they relate to his treatment process.

The pH and the zeta potential of the rapid mix effluent are the most important and informative data in a water treatment plant. Coagulation takes place in the flash mixer. It is here that the degree of coagulation of all particles is determined and the chemical and physical properties of the floc are fixed. The rapid mix, including chemical introduction techniques, is the most important unit operation in a water plant. Inefficiencies and design weakness may be overcome to some extent by over feeding coagulant chemicals.

Turbidity measurement of the settled water gives the operator qualitative information concerning the "load" on the filters. Also, it will sound an alert should a basin "turn-over" occur.

Turbidity of the filtered water is, of course, the prime, non-bacteriological measure of success in a municipal water treatment process. Suggestions for finished water quality goals have been outlined by AWWA Task Force 2640-P in "Proposed Quality Goals for Potable Water". They propose that the public be served with water containing less than 0.1 unit of turbidity and 3 units of color. The author

is in complete agreement with these proposals and further feels that any process that does not meet them consistently should be considered deficient.

Turbidity and pH measurements on the high service water should be recorded and placed in the records for the confirmation of the health department and for use in servicing customer quality complaints.

#### OPERATING TECHNIQUES

Participation in many plant startups and subsequent operations has led to a number of miscellaneous observations. They are offered here as personal opinions.

1) Competent, conscientious operators are hard to find.

If you have some, treasure them and train them. Good training programs pay off in product quality, plant efficiency and lower maintenance costs.

2) Many operators while very competent mechanically and in routine laboratory techniques, have only a slight concept of the water treatment process or of the chemical and physical parameters involved in coagulation, flocculation, settling and filtration. This is probably the result of weakness in compartmentalized training programs that concentrate on the mechanical aspects of the plant and routine analysis in the laboratory. There should be more effort toward relating the function of the equipment and the laboratory results to the water treatment process.

- 3) Rarely do two operators, even in the same plant, use the same backwash procedures. Effective backwash is the most important factor in satisfactory long-term operation of filters, and these procedures should be consistent, at least in the same plant.
- 4) For a number of years, the trend has been to do away with rewash after backwash. The use of turbidimeters on filter effluents has shown the value of rewash in avoiding contamination of the water in the clearwell with turbidity.
- 5) The addition of pH affecting chemicals just prior to filtration will change the chemical characteristics of the floc and lower the quality of the filter effluent.
- 6) There are no advantages to excessively long runs. Termination at a maximum of 72 hours makes for easier and more effective backwashing which results in longer filter media life.

#### SUMMARY

A water treatment plant is, in fact, a "food grade" chemical processing plant, in which the operator has no control over the quality of the raw material. Increasing pollution of our surface water supplies and public demands for a better product make all aspects of controlling filter plant operation of critical interest. First, as the water treatment problems become more complex, process design may well become a specialty in the sanitary engineering field.

Secondly, plant process control is beginning to receive the emphasis. Last and far from least in importance, operator training is being appreciated and expanded. Examples of this are the recently announced AWWA Workshops "Getting the Most Out of Your Treatment Plant". This course, financed by the Water and Waste Equipment Manufacturers Association, has been given first in Pennsylvania and then California. During the coming year it will be offered at a number of locations at the request of the local sections.

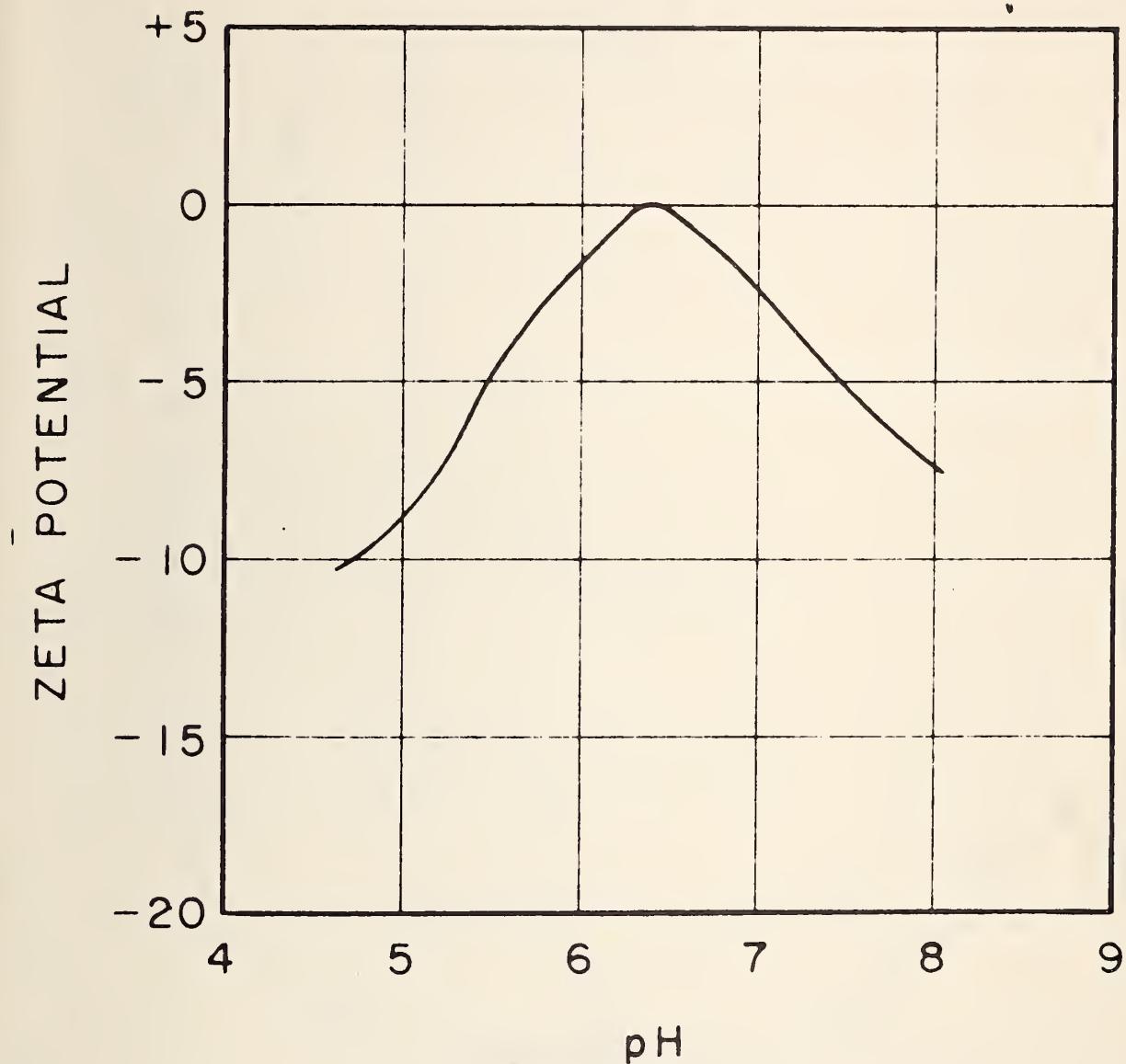


Fig. I. ZETA POTENTIAL AT VARYING pH BUT CONSTANT ALUM DOSAGE

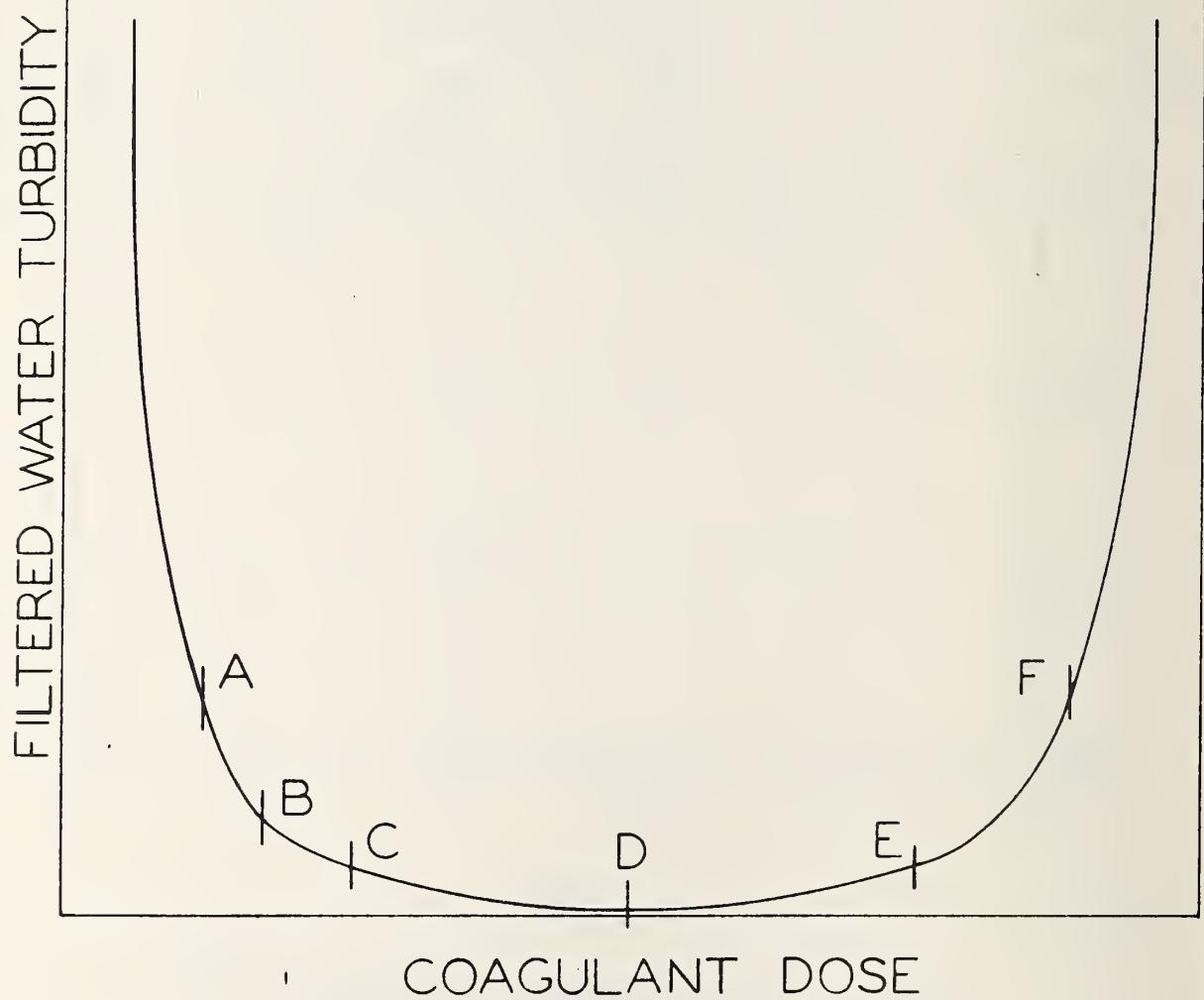
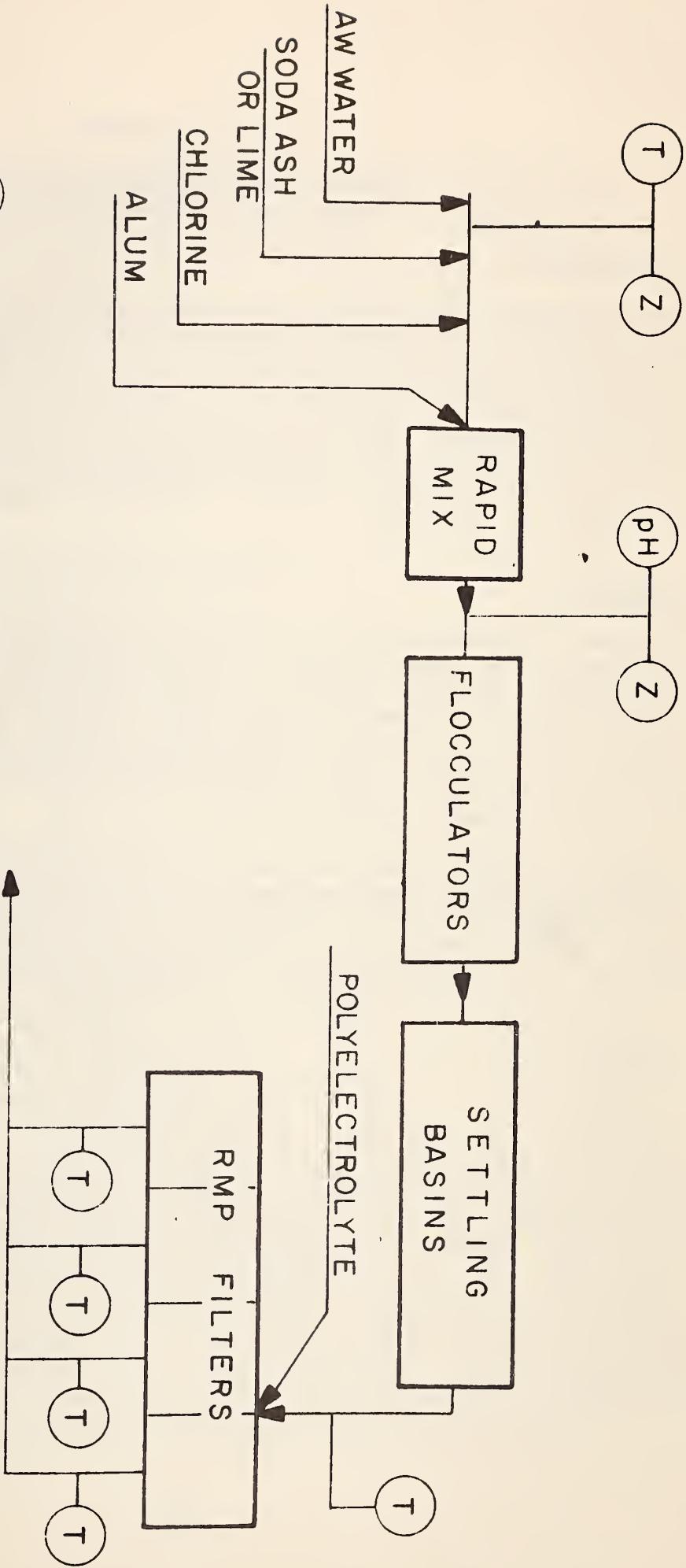


Fig. II. TURBIDITY IN FILTER EFFLUENT WITH INCREASING COAGULANT DOSAGE



(T) TURBIDITY MONITORED AND RECORDED

(pH) pH MONITORED AND RECORDED

(Z) ZETA POTENTIAL MONITORED

FIG. III. SCHEMATIC DIAGRAM OF A TYPICAL WATER PLANT SHOWING CHEMICAL FEED LOCATIONS AND MONITORING POINTS FOR A "HIGH-RATE" INSTALLATION

## COAGULATION CONTROL

Walter R. Conley and Richard H. Evers  
Presented by Hank Mueller

### INTRODUCTION

The accurate and precise control of coagulation is the most important step in the operation of a water filtration plant. After coagulation is correct, intelligent filter management is relatively simple. For a water supply of rapidly changing characteristics, coagulation control is also the most difficult step in plant operation. Lack of control procedures other than by rough visual estimate of floc size and character has, in the past, made precise control impossible. In recent years, however, a number of methods have been developed for more precisely identifying good coagulation. Discussion of some of these methods is the purpose of this paper.

### DEFINITIONS

The terms coagulation and flocculation are often used interchangeably. For purposes of this paper, coagulation will be considered to comprise the results of electrical and chemical action brought about in water following the addition of coagulating chemicals. Coagulation involves the reduction of surface charge and the formation of complex hydrous oxides. These reactions are nearly instantaneous; the only time required for their completion is that necessary for dispersing these chemicals throughout the water. Shortly after mixing is achieved, coagulation is complete.

Flocculation, on the other hand, consists of the bonding together of the coagulated particles following the removal of the forces that kept them apart, and the entanglement of the particles by the precipitating hydrous oxides. Growth of the particles requires the passage of a definite interval of time. These definitions are arbitrary, but it is necessary that a definition be made so that the meaning of the following sections is clear.

### COAGULATION

To illustrate the relationship between coagulation and flocculation, let us consider the following cases; the first dealing with a colorless water, the second with a highly colored water: The raw water from the Upper Columbia River during the month of January usually has a temperature of about 2°C and a turbidity of less than 2 Jackson Units. If this water is filtered without the addition of alum, the turbidity is not removed. On the other hand, the addition of only 5 mg/l of alum causes rapid coagulation and although there is no visible indication that particulate matter in the water has been flocculated (no visible floc), passage through a filter removes the turbidity. For the development of a large floc in this cold, clear water, the addition of 15 to 20 mg/l of alum is required together with a period of 20 minutes of gentle agitation.

Similarly, muskeg water from British Columbia containing 500 Jackson Units of color at a temperature of 3°C can be coagulated with 100 mg/l of alum. The treated water can be filtered to give a clear, relatively colorless effluent (10 units) within 5 minutes after the alum has been added. Development of a large floc in this same water requires at least 15 minutes agitation.

As exemplified by the Columbia River water, an alum dosage which produces a clear filtrate may not be sufficient to produce a settleable floc. It is fortunate that waters which are difficult to flocculate because they are clear and cold, can be coagulated and filtered without the need to develop a large settleable floc. If enough alum is added to give a large floc in water of this type, floc strength is seriously impaired and can lead to premature filter breakthrough. For purposes of this paper, breakthrough is defined as the appearance of properly coagulated material in the filter effluent.

Data showing the effect of alum feed on floc strength, as measured by depth of penetration in a filter bed, are shown in Figure 7. As will be noted, the higher alum dosage caused the floc to penetrate more deeply into the bed. This is evidenced by the higher percentage of headloss in the lower part of the bed. The lower alum dosage resulted in less penetration, as evidenced by the greater percentage of headloss near the top of the bed. This pattern of increasing penetration as a function of increased alum feed beyond the minimum required for complete coagulation has been observed on all waters tested. When dealing with a low turbidity water, the use of excess coagulant will result in premature breakthrough, and the plant filters cannot perform efficiently.

In a very low turbidity water, there is not sufficient particulate matter to form a large floc in any reasonable time. As the amounts of particulate matter increase, however, the collisions between particles are more frequent and the growth of the floc is faster. Moreover, as turbidity rises to about 50 or more units, we often find that the minimum alum dosage to achieve coagulation will produce a large, settleable floc.....or stated in another manner, the alum requirement for good filtration and for good settling are the same.

A report on coagulation and filtration of Lake Erie water without flocculation or settling was made by the U.S. Public Health Service (1). This paper showed that the relatively clear Lake Erie water could be treated with alum and filtered at 6 gpm per square foot to give high quality filtered water and satisfactory filter runs without flocculation or settling.

More highly turbid waters can also be coagulated very quickly and filtered to give a clear effluent, whereas development of a fast settling floc requires mechanical agitation in order to grow the floc to a size at which settling will be optimum. Table 1 shows laboratory data concerning coagulation of a few natural waters and the results obtained by filtration.

#### SETTLING

Some surface water supplies can and should be clarified by adding chemicals and filtering directly without mechanical flocculation or settling. Other supplies will require settling before filtration for economical operation.

The use of high performance mixed-media filters makes it practical to consider eliminating the settling step for waters which regularly contain 100 units of turbidity and organic color. Although more than 100 units can be handled without impairing effluent quality, the filter runs will generally be shortened in proportion to turbidity loading. The frequency and time duration of higher turbidities and probable plant export water demand should be considered in evaluating the need for settling. Laboratory tests of coagulation, flocculation and filtration can be used to determine whether or not settling is desirable.

#### MONITORING BY VISUAL MEANS

The most common method of monitoring coagulation is by jar tests and visual observation. This method gives very satisfactory results when applied to one particular kind of water - that containing only a moderate amount of organic turbidity and 100 or so units of inorganic turbidity. When dealing with waters of this sort, a sharp end point can be reached by visual determination. For low turbidity water, and waters containing large amounts of organic material, no sharp end point exists. It is usually difficult to determine from the appearance of the sample whether adequate settling and filtration will result. Thus, although excellent control can be achieved under certain conditions by visual monitoring, it is nonetheless true that at other times visual control becomes a guessing game, with each observer seeing characteristics which may or may not be reflected in plant performance.

#### MONITORING BY ELECTROPHORESIS

The electrophoretic cell has been used to measure coagulation (2). This method involves measuring the charge on particles by means of observing their rate of movement toward electrodes. It is generally agreed that this method is not easily adapted to the typical treatment plant because of the considerable degree of technical skill required to make the measurements and the amount of interpretation required to make the data useful. Until this method can be automated to enable recording of results, it will be of limited value as a control device although it will continue to be a useful tool in research studies involving coagulation. The limitation of charge measurement as an index for coagulation will be discussed in more detail under the streaming current detector.

#### MONITORING BY STREAMING CURRENT DETECTOR

It has been reported that the streaming current detector can give the same qualitative information concerning surface charge as the electrophoretic cell. At least one company is marketing a streaming current device on which the output can be recorded. The instrument has been used experimentally for two or three years with reportedly good results. However, like the electrophoretic cell, the data produced is entirely relative rather than absolute and requires considerable interpretation to make it useful. This requires correlation with recorded plant performance to optimize results (3). In other words, the usual indices of clarity of the filtered water must be obtained and these data correlated with the instrument readings.

## MONITORING WITH PILOT FILTERS

A far better method of monitoring the coagulation process is to filter a sample of the plant treated water, following addition of coagulating materials, through a pilot filter under conditions which preclude filtration failure. The turbidity of the pilot filter effluent can be monitored continuously and accessory instrumentation can be used to control feed of the coagulant and other chemicals as well as to alert plant operators in the event that turbidity climbs above some predesignated value.

By sampling plant treated water (raw water after chemicals have been added) the pilot filter system provides "early warning" of improper coagulation conditions. The time lag in the pilot filter system is normally limited to 10 minutes. This is the time it takes for the effect of a dosage change (or raw water condition change) to be noted by an increase or decrease in the pilot filter effluent turbidity. The need for the pilot filter system is apparent to any operator contending with a raw water supply which changes rapidly in nature. To illustrate the point, Table 2 shows data for a surface supply at Oakland, Oregon. The plant is owned by Oregon Water Corporation and is operated under the direction of Mr. Alton Andrews. It will be noted that the turbidity of the raw water changed from 75 units to 525 units in about 14 hours. The alum feed was changed from 22 ppm to 65 ppm during the same period. The operator was using filter effluent turbidity for control. It will be noted that the effluent turbidity was held between 0.1 and 0.4 Jackson Units. Such a water is not unusual; there are many waters that are worse.

The pilot filter coagulant control system can be used either to indicate coagulation conditions or to control them automatically. Figure 6 illustrates a unit which provides monitoring of coagulation without automatic control. Two pilot columns are used to allow monitoring of coagulation on a continuous basis. The pilot filter effluent is monitored by turbidimetry equipment sensitive to changes of 0.01 J.U. at a 0.1 J.U. value. Alarms, both visual and audible, are provided if the pilot filter turbidity exceeds specified limits. If a high turbidity alarm is sounded, the operator knows that he must increase the amount of coagulant feed. The effect of the feed increase can be noted within 10 minutes, the time lag in this system. The pilot filter system provides a means for optimizing, and, therefore, minimizing coagulant feed. Plant effluent clarity can readily be maintained at desired values.

Equipment should also be provided for monitoring the effluent turbidity of the plant filters. This provides proof of the pilot filter predictions and assures proper plant performance.

Use of the pilot filter method of coagulation monitoring makes it easier for the plant operator to manage his filters in an intelligent manner. Techniques of filter management have been covered in the Journal (4, 5, and 6).

As with plant filters, filtration failure (or breakthrough) of the pilot filters can occur unless proper steps are taken. Such a failure will cause the coagulant feed to be adjusted without need. The possibility of filtration failure in the pilot filter system is minimized by the following precautions:

1. The filter can be constructed of very fine media to promote highly efficient filtration.
2. An excess of floc strengthening chemical can be added as the water enters the pilot filter. Enough is added to insure that the strength of the floc is sufficient to prevent breakthrough.
3. The filter can be backwashed on a short cycle to insure that it is always relatively clean.

Thus, if turbidity appears in the water leaving the pilot filter, either the coagulant dosage is too low or the pH is in the wrong zone for proper coagulation.

For most waters, those containing little organic matter, the pH range for coagulation is normally between 6.5 and 7.5. Those waters which contain considerable organic coloring material have a lower optimum pH for coagulation, sometimes as low as 4.5. One should know the pH operating limits for the raw water being used. Assuming sufficient alkalinity in the raw water, the pilot filter effluent provides a simple means of establishing the proper pH zone. High clarity water (less than 0.2 J.U.) will be produced only when coagulation is carried out in the proper pH zone. If a water with very low alkalinity is being treated, adjustment of the raw water alkalinity may be required for optimum coagulation. The pilot filter system will indicate whether or not the conditions are proper and adjustments in either or both the coagulant and alkalinity adjustment chemicals can be made and the effect noticed within minutes.

#### CASE HISTORIES

Having considered turbidity monitoring and the use of pilot filters, let us cite a few brief descriptions directed toward an understanding of the value of these methods under certain specific conditions of plant operation.

#### WHEN A BREAKDOWN OCCURS

Figures 3 and 4 show the operating charts from a water treatment plant in the midwest. Chart 3 is the pilot filter chart. Note that the effluent turbidity is normally between 0.1 and 0.2 units.

At approximately 5:15 a.m. on the day represented by this chart, the operator has noted that the alum feeder jammed (this is a reconstruction after the fact). The turbidity of the filtered water leaving the pilot filter remained high. The operator continuously turned up the alum feed until about 6 a.m. at which time he learned that lumps of alum were preventing the volumetric feeder from delivering sufficient alum to the solution pot. He was thereafter able to remedy the situation with little difficulty. Although the operator should have detected the feeder trouble more quickly than he did, no serious damage was done.

At about 6:20 a.m., the turbidity of the pilot filter effluent took a sharp turn for the better and by about 7:00 a.m. conditions were back to normal.

During this same period, the turbidity of the effluent emerging from the plant filters began to climb, until about 6:45 a.m. it had reached 2 Jackson Units. However, by this time the trouble had already been diagnosed and corrected, and the situation had been returned to normal by about 8:00 a.m.

Early warning, in this case, prevented the too common occurrence in which the operator has an eight or ten hours' supply of filtered water which is outside specifications.

#### WHEN THERE IS NO BREAKDOWN

Figure 5 shows strip charts from an industrial water treatment plant on the Columbia River. The desired control point is between 0.5 and 1 unit of turbidity on plant filtered water.

The top chart shows the turbidity from the two pilot filters. Note that there is a slight change in turbidity when the pilot filters switch in their monitoring sequence. The plant filtered water (bottom chart) is held uniformly between the desired control points.

#### HANDLING A TURBIDITY SURGE

Table 3 shows operating data from a treatment plant. Note that the operator remained in control of coagulation although turbidity ranged in a single day from 2 to 1500 Jackson Units. It should also be noted that the turbidity of the settled water was acceptable, ranging from a low of 1.2 to a high of 6.0, in spite of the wide variations in raw water turbidity. The effluent from the pilot filters ranged from 0.2 to 1.0 Jackson Unit while the plant effluent varied from 0.2 to 0.3 units.

#### ORGANIC COLOR REMOVAL

For waters high in organic color, the turbidity of the filter effluent provides an excellent index of color removal. This is so because the color-producing materials are held in suspension (or solution) until sufficient alum is added to coagulate them. Data for one natural water are shown in Table 4.

#### FLOCCULATION WITH NON-IONIC POLYMERS

In order for the pilot filters to work properly, a non-ionic polymer must be used in excess to avoid filtration failure as explained in a foregoing section of this paper. Will this excess of polymer interfere with the coagulation monitoring function? As coagulation is defined in this paper, the answer is clearly "no." The non-ionic polymers are not coagulants, but do act to flocculate particles of relatively large size. The rough dividing point is the size particle which will settle, without chemical addition, in a 24-hour period. These particles have essentially no effect on the coagulant requirements (alum feed), but can be flocculated by the non-ionic polymers.

Although over 100 natural waters have been tested, one has not been found which can be successfully coagulated with a non-ionic polymer. On the other hand, such suspensions as activated carbon and Fuller's Earth can be flocculated readily with the non-ionic polymers. There is always a cloudy supernatant above the flocculated material.

#### AUTOMATIC CONTROL OF COAGULATION

The control system illustrated in Figure 1 has been utilized successfully in automatic control of the chemical feeds at an unattended 1 MGD water treatment plant at Mill City, Oregon, owned by Pacific Power and Light Company and operated under the direction of Mr. Chet Elston.

It will be noted that a sample of the plant water, treated with alum and soda ash, is pumped upflow through a column of calcium carbonate, then through a pilot filter to a turbidimeter. The calcium carbonate maintains the pH between 6 and 7 (optimum for this water), even if the alum is fed in sufficient quantity to react with all of the alkalinity present in the raw water (30 mg/l). The calcium carbonate becomes, then, a simple automatic pH control device. If the pilot filter effluent shows high turbidity, the alum feed is incorrect because the other variable (pH) is under control. A non-ionic polymer is added to the pilot filter to minimize the chance of a filtration failure. The effluent from the pilot filter is passed through a turbidimeter and the signal from the turbidimeter controls the speed of the alum feed pump. Concurrently, the feed of the soda ash is adjusted in proportion to changes in alum feed.

A strip chart from this plant is shown in Figure 2 (the upper line on this chart represents the effluent turbidity from the pilot filter). As the strip chart indicates, there are actually two pilot filters used at Mill City; one filter is in operation and is available for readout while the other is engaged in the backwash process. It should be noted that the effluent turbidity from the pilot filters is always slightly higher than that from the plant filters (ranging from 0.3 to 0.7 units) because the plant filters have an appreciably longer run time than the pilot filters. The accumulated floc in the plant filters gives a somewhat increased filtration efficiency and the final turbidity is thus somewhat lower.

#### SAFEGUARDS

It is realized, of course, that no system is completely foolproof. However, in order to make this plant approach the ideal as closely as possible, two safeguards have been built into its operation.

1. If the turbidity of the pilot filter effluent exceeds a certain limit (2 units) a red warning light which can be seen from the plant window is flashed to alert the operator; he can act at discretion.
2. A circuit can shutdown the plant if plant filter effluent turbidity exceeds a preset limit (3 units).

From time to time, there have been some failures at the Mill City plant. On one occasion, over a holiday weekend, there was failure to provide sufficient chemical to the feeders. Again, a sample pump failed when it became airbound. Another time a bolt was dropped into the electrical gear, causing the operation to become short-circuited. These incidents which, strictly speaking, should not occur merely prove that the Mill City plant, like all others, is run by human beings who will make mistakes. Instrumentation at Mill City is designed to eliminate, if not such minor incidents themselves, at least their most deleterious effects. A system of alarms dependent upon both the pilot filter turbidity and the plant filter turbidity will, first alert the operator to take immediate action and second, shut down the plant automatically should the operator fail, for any reason, to correct the trouble.

#### SUMMARY

Coagulation is arbitrarily defined as the nearly instantaneous reduction of surface charge and the formation of hydrous oxides after a coagulant is added to raw water. Flocculation is defined as the bonding together of the particles following coagulation.

Coagulation is the most important and difficult step in the operation of a water treatment plant where raw water conditions change frequently. A measurement to determine whether or not coagulation has been achieved is a necessary first step in coagulation control. Of the methods in use today (electrophoresis, jar tests, streaming current and pilot filters) it is believed that the pilot filter system has the advantage of being the only method which measures directly the variable of interest to the plant (filtered water turbidity). The other methods measure other variables which often (but not always) are related to filtered water turbidity.

The pilot filter system provides "early warning" of improper coagulation conditions. It further allows the quick and accurate evaluation of coagulant dosage changes. Coagulation control can be maintained even under rapidly changing raw water conditions. Chemical dosages can be optimized and, therefore, treatment costs minimized for the production of plant waters with desired effluent clarity.

The use of the pilot filter system to control coagulant and related chemical dosages brings full automatic control of water plant operation closer to reality. One such plant has been operating satisfactorily for over one year.

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TABLE 1

Coagulation of Several Natural Waters

Raw Water			Filtered Water*	
Turbidity Jackson Units	Color Standard Units	Temp °C	Turbidity Jackson Units	Color Standard Units
2	5	3	0.09	5
18	35	4	0.14	5
18	35	22	0.024	5
18	35	7	0.12	5
350	35	6	0.15	5
2	500	3	0.25	10

\* In each case, filtration was completed within five minutes after coagulant addition.

TABLE 2

Operational Changes on a Flashy River

Time	Turbidity Raw Water Jackson Units	Turbidity Filtered Water Jackson Units	Alum mg/1
7:30 p.m.	75	0.1	22
8:10 a.m.	300	0.1	48
9:45 a.m.	525	0.4	65
6:00 p.m.	300	0.1	48
9:00 p.m.	200	0.1	36
9:00 a.m.	150	0.1	26
8:45 p.m.	125	0.1	20

TABLE 3

Operational Data

Turbidity Jackson Units Raw Water Daily Range	Turbidity Settled Water Jackson Units	Effluent Turbidity Jackson Units	Control Bed Turbidity Jackson Units	Average Alum Feed mg/l
2.5	1.5	0.2	0.2 - 0.4	26
3.0	1.2	0.2	.20 - 0.6	27
6	1.6	0.3	0.3 - 0.9	24
2-1500	1.3	0.2	0.2 - 0.4	28
150-2200	4.0	0.2	0.2 - 1.0	68
12-100	6.0	0.2	0.2 - 0.9	58
8-1100	3.0	0.2	0.2 - 1.0	140

TABLE 4

Association Between Turbidity & Color Removal

Coagulant (Alum) Dosage mg/l	Floc Appearance	Filtered Water	
		Turbidity Jackson Units	Color Standard Units
0	---	1	80
15	None	2.2	20
20	Small	0.75	7
25	Large	0.35	6
30	Large	0.20	3

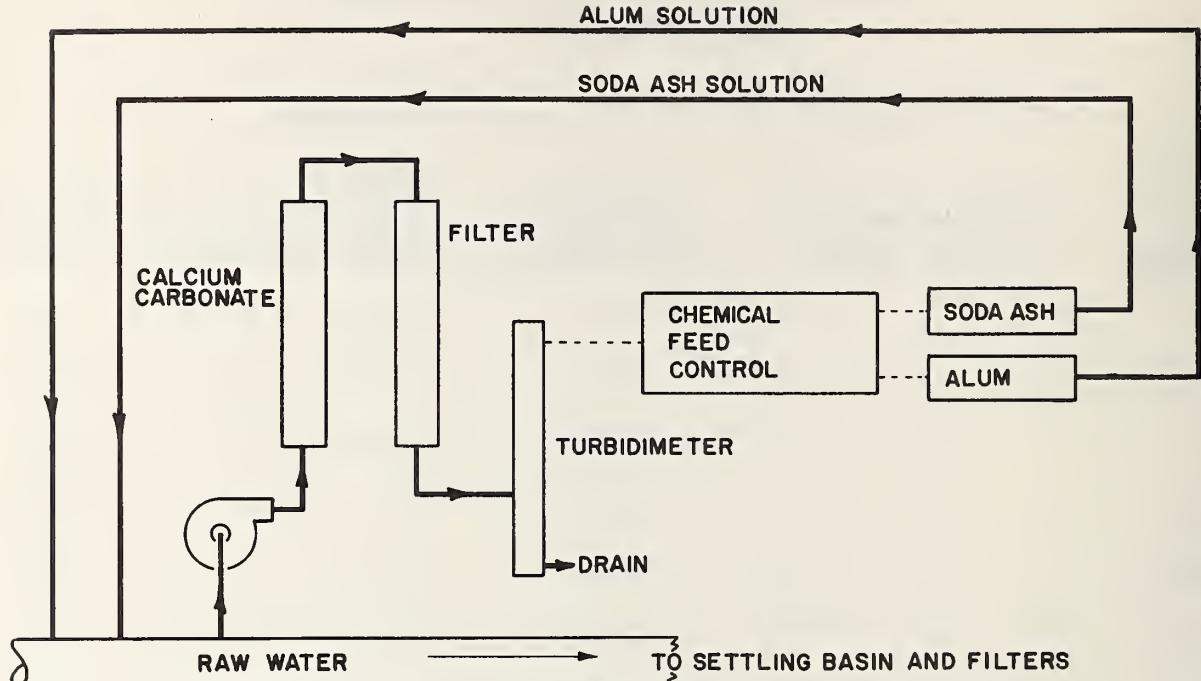


FIG. I  
AUTOMATIC COAGULATION CONTROL

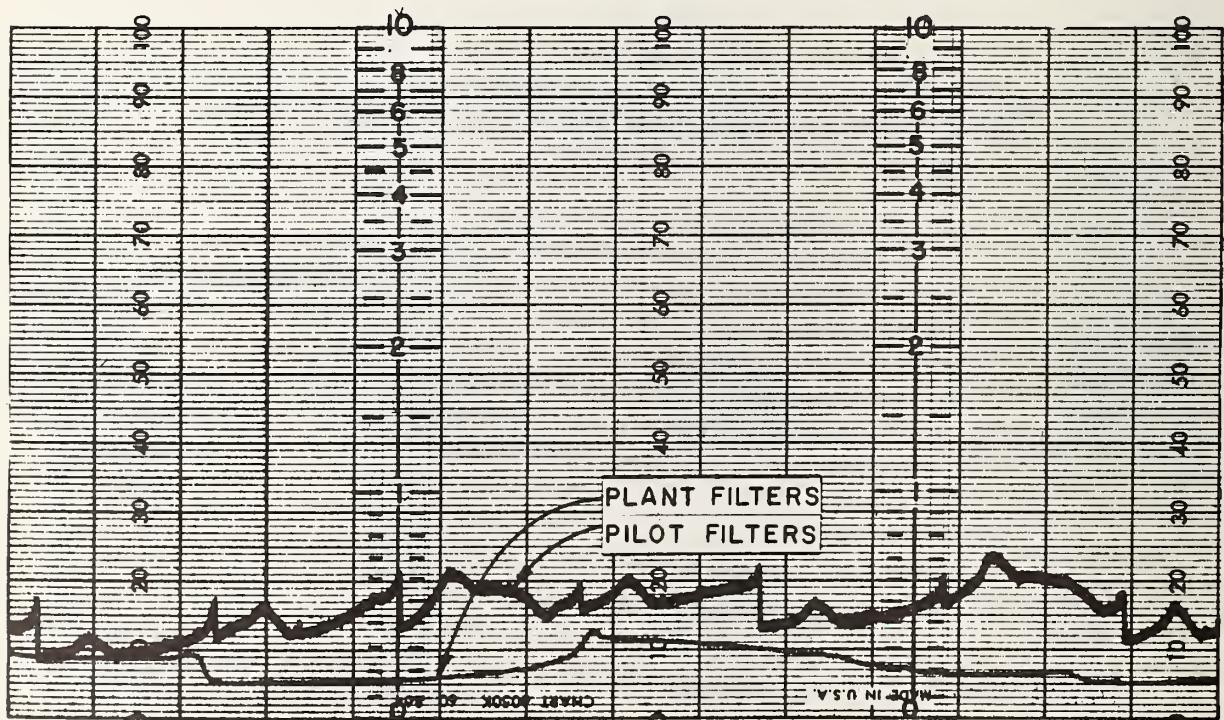


FIGURE 2  
TURBIDITY CONTROL CHARTS  
MILL CITY, OREGON

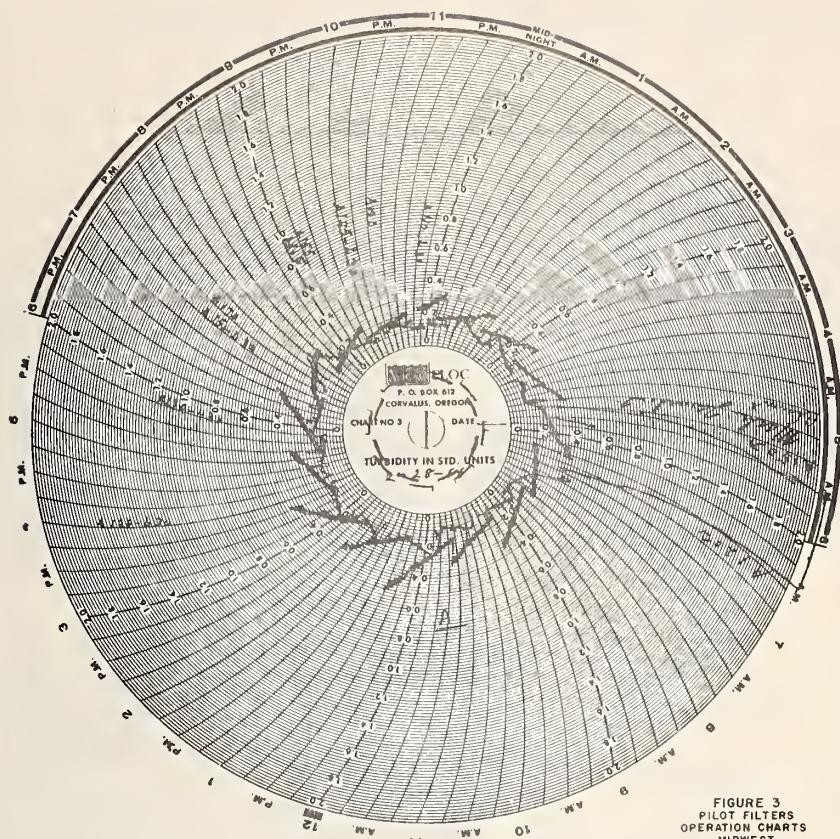


FIGURE 3  
PILOT FILTERS  
OPERATION CHARTS  
MIDWEST

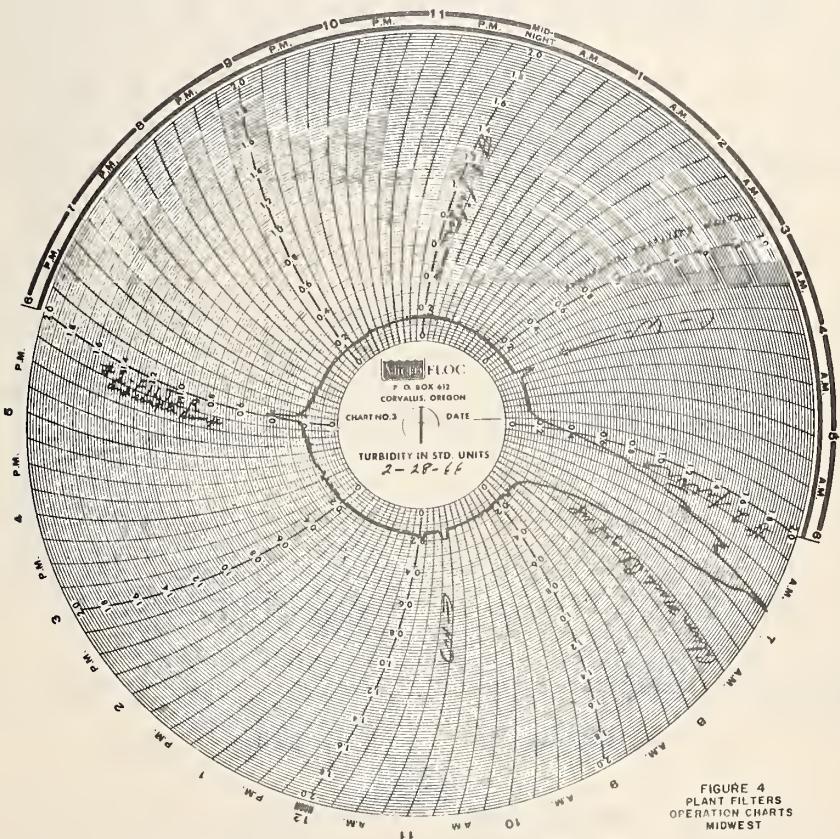


FIGURE 4  
PLANT FILTERS  
OPERATION CHARTS  
MIDWEST

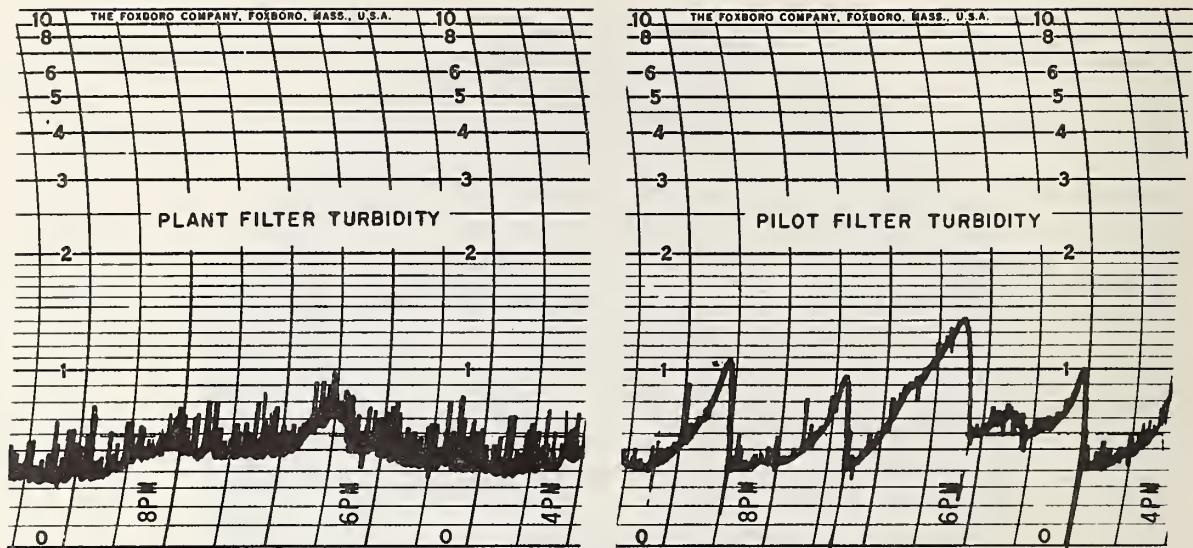


FIGURE 5  
PLANT CONTROL CHARTS  
COLUMBIA RIVER

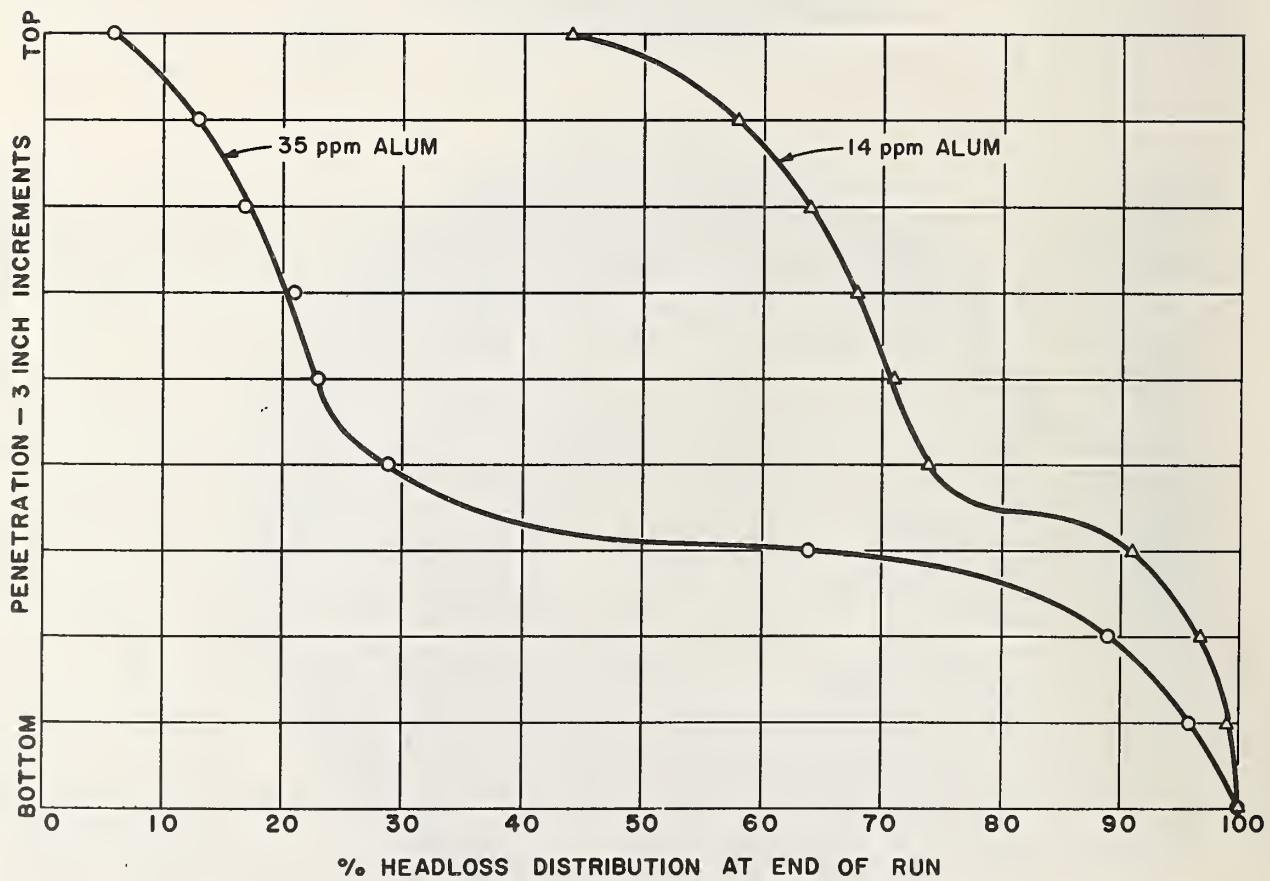


FIGURE 7  
THE EFFECT OF ALUM FEED ON FLOC PENETRATION INTO A FILTER

RAW WATER CONTAINED 3 UNITS OF COLOR AND TURBIDITY AND WAS FILTERED AT 12°C THROUGH A 30-INCH DEEP MIXED-MEDIA BED COMPOSED OF 10% GARNET, 30% SAND, AND 60% COAL.

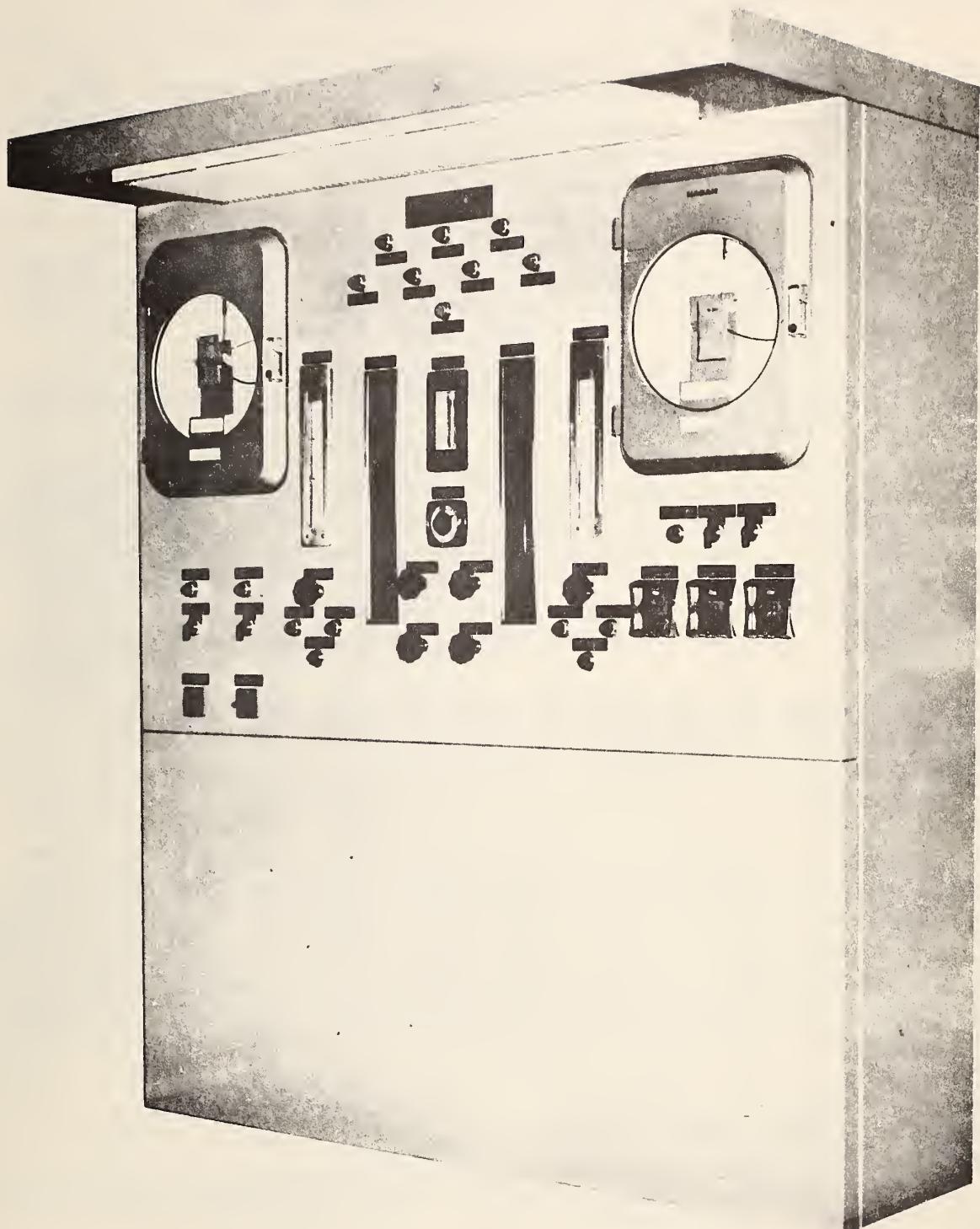


FIGURE 6  
COAGULANT CONTROL CENTER

## TURBIDITY MONITORING

Presented by Claus J. Weidner  
Based on material prepared by -  
Clifford C. Hach, H.R. Tool and C.T. Weidner  
Hach Chemical Company - Ames, Iowa

Perhaps no single analytical determination has had more influence on the design, operation, and economics of water treatment than the measurement of turbidity; particularly the measurement of LOW turbidities in clarified and filtered water.

Before about 1958, there were no satisfactory low range turbidimeters available for continuous measurement. Very few laboratory type low range turbidimeters were used, and then only for research and not for plant control purposes. The importance or potential value of turbidity measurement in the control of water treatment plant operations was virtually unknown before this time.

After about 1958, satisfactory low range turbidimeters became available, and they became a stimulus for the development of the concept of rapid rate filtration. It was soon found that turbidity measurement was the best available index for determining the dosage rate of clarification chemicals and with turbidimeter control, usually great savings in chemicals were achieved.

The advent of the turbidimeter also served as a stimulus to development of multi-media filter beds which are proving capable of a very high rate of filtration.

Lastly, the advent of turbidimeters has resulted in a general improvement of the clarity of finished water from water treatment plants - so that at this time the maximum permissible limit of turbidity of the U.S. Drinking Standards is being lowered from five to one Jackson Turbidity Unit. Some plants suggest the drinking water standards should be lowered to 0.1 JTU because it is possible to produce water of this high quality with the present day coagulants, coagulant aids, modern filters and turbidimeters.

### DEFINITION OF TURBIDITY

The American Public Health Association Standard Methods state: "Turbidity should be clearly understood to be an expression

of the optical property of a sample which causes light to be scattered and absorbed rather than transmitted in straight lines through the sample."

Turbidity is caused by the presence of suspended matter, such as clay, mud, algae, silica, rust, bacteria, calcium carbonate, etc., which cause the liquid to appear cloudy, muddy, or turbid. The Jackson Turbidity Unit (JTU) is the standard unit of measurement and expression of turbidity.

The Jackson Candle Turbidimeter shown in this slide (Slide No. 1) was the basis for turbidity measurements in Jackson Turbidity Units. The apparatus consists of a special candle, and a flat-bottomed glass tube which has been graduated in JTU, plus a suitable holder for the apparatus.

The measurement is made by slowly pouring the turbid sample into the glass tube while observing the image of the candle flame from the open top of the tube. Pouring the sample is continued until the image disappears into an uniform glow. The glass tube of the turbidimeter is graduated so that a reading can be made of the JTU corresponding to the depth of sample in the tube at the point of image extinction.

### NEPHELOMETRY AND ABSORPTOMETRY

Two measuring systems are available for measuring the amount of solid material in colloidal suspension - or turbidity, through the measurement of transmitted light - or absorptometry, or through the measurement of scattered light - or nephelometry.

This slide (Slide No. 2) shows a diagram of an absorptometer. Its application is limited to high turbidity measurement. The following slide (Slide No. 3) shows the response curve of an absorptometer. As you can see, the response is negative, i.e., the signal decreases with increasing turbidity, the maximum signal is at zero turbidity, the response is non-linear, and its range depends on the physical design of the instrument, i.e., the length of its light pass. For example, with a light path length of three feet only a ten per cent absorption is obtained with one JTU turbidity. Also, very importantly dissolved color present in the sample being analyzed will also absorb light, and thus register as turbidity.

The following slide (Slide No. 4) shows the diagram of a Nephelometer in its basic and conventional design. The response curve of the nephelometer is shown in the next slide (Slide No. 5).

### RESPONSE OF NEPHELOMETER

You can see that the response of the nephelometer is zero at zero turbidity and that a linear response is obtained beginning at zero and extending to a certain turbidity, after which the response begins to level off. In a conventional nephelometer further increases in turbidity cause a decrease in response and finally the instrument "goes blind" at a high turbidity value. The reasons for the leveling off of the response and "going blind" are that at high turbidity values the sample becomes increasingly opaque and the light cannot penetrate it. The shorter the light path in the nephelometer, the higher the turbidity that can be measured.

Because the output signal from a nephelometer is zero at zero turbidity and increases directly with respect to turbidity, any desired degree of sensitivity can be obtained either by increasing the brightness of the light that is passed through the sample, by increasing the sensitivity of the photocell system, or both. Thus, nephelometers can be readily set up with a full scale range of as little as 0 - 0.2 JTU and turbidities in the hundredths of one JTU can be accurately measured.

### NEPHELOMETER DESIGN

The most serious disadvantage of a nephelometer is the matter of stray light. Any scratches, imperfections in the glass windows, dirt, film, air bubbles, or condensation on the glass, will scatter light: some of which usually reaches the photocell and gives a positive error to the turbidity measurement. This is a very serious problem, especially when very low turbidities are being measured. This one problem alone prevented development of practical continuous nephelometers until recently.

To overcome the problem of stray light caused by glass windows in a nephelometer, Hach Chemical Company adopted for its design of nephelometric continuous flow turbidimeters, a principle from the glass manufacturing industry. In this industry, it was known that the upper surface of molten glass, when poured on a flat surface, would smooth itself out and attain a polish and brilliance far greater than was obtainable by grinding and polishing.

The process of manufacturing glass by a float process was developed to take advantage of this principle.

It was reasoned that if the light was admitted through the upper surface of the water sample in a nephelometer, the problem of light scattering by the window could be overcome. The adoption of this principle resulted in the development of two types of turbidimeters that performed the measurement of very small, as well as very high, amounts of turbidity successfully.

This following slide (Slide No. 6) shows the Hach Low Range Turbidimeter consisting of a copper tube that serves as the sample vessel and a light trap. At the bottom of the tube is provided a sample inlet. The overflow drain is located in the upper section of the tube. Mounted on the lid of the instrument is the sensor head consisting of a light source with focusing lens and two spoonlike photocell assemblies, whose heads are submerged below the water surface. The flow of water through the instrument is adjusted until a smooth flowing surface is obtained through which the light beam is projected into the water column. Turbidity particles in the water stream reflect and scatter some of the light from the light beam at a right angle to this beam. This light is measured by the photocells and the output is read over a panel meter. This instrument has become the most successful turbidimeter for continuous low range measurements. Its lowest full scale range is 0 - 0.2 JTU calibrated to read as little as 0.01 JTU. The other full scale ranges are 0 - 1, 0 - 10, and 0 - 30 JTU.

The following slide (Slide No. 7) shows the Hach Surface Scatter Turbidimeter.

In this type of turbidimeter, the photocells are mounted above the surface of the water. The light beam is projected at an angle of about  $10^{\circ}$  from the surface of the water. Some of the light enters the water, due to refraction, and is absorbed by the elongated turbidimeter body. Another portion of the light is reflected and absorbed by the turbidimeter case.

Particles of turbidity scatter light in all directions and the vertically scattered light is registered by the photocells and indicated on the meter.

This "Surface Scatter" system is the most versatile covering all ranges of turbidity. Its high-range capabilities have been used by industry to monitor dye particles from filter presses in actual control of the concentration of materials in suspension, such as carbon black. This system is also used by the Chicago Waste Treatment Plant to monitor the effluent from its final settling tank.

Raw water coming into a water plant is often monitored by this unit since the turbidity of water may vary throughout the range of the instrument due to upstream variations.

## APPLICATIONS

Only after the instruments became available did their true value become apparent. For example, water plants which were once thought to be of inadequate capacity and consequently were scheduled for reconstruction were found to have added capacity with the use of high-rate filtration. In addition, they were quite often operated at a lower unit cost because of their ability to control coagulant chemical feed. (Slide No. 8)

The low-range turbidimeter has been found to be ideal for water monitoring and control. Typical uses include the control of coagulant feed, the effect of filter rate on clarity, the effect of filter design on filter efficiency.

A relationship between the feed rate of clarifying chemicals and residual turbidity is illustrated in the following slide (Slide No. 9). It should be noted that as the feed concentration increases there is a very rapid decrease in turbidity until a levelling occurs. After the levelling a further increase in the coagulant feed results in very little decrease in the turbidity. Therefore, a control point is established and the turbidimeter actually controls the coagulant feed rate.

Use of a turbidimeter to control coagulant feed at the General Electric Company's Hanford, Washington plant has been described by Pitman and Conley. Pitman showed a savings of \$250,000 per year in chemicals alone. (Slide No. 10)

Turbidimeters have been found to be very helpful in the routine operation and management of filters. Traditionally filters were equipped with head-loss gauges and the time required for backwashing was determined by the degree of head-loss that developed. The residual turbidity during a filter run is represented by a typical curve in this slide (Slide No. 11).

Immediately after backwashing there is a short period of relatively high turbidity which may last from 15 minutes to one hour. This is followed by a low turbidity value which remains constant for hours before giving way to a gradual increase in the turbidity of the filter effluent. Backwashing is usually deemed necessary when the turbidity increases to an unacceptable value.

This point of breakthrough does not coincide with any particular value of loss of head. Therefore, backwashing a filter at a point of a particular loss of head is not a rigorous or necessarily the proper point at which to backwash.

In a recent study, Geis, Pitman and Wells used a turbidimeter to relate turbidity to the use of coagulant aids. By this correlation, the proper addition rate for the coagulant aids was determined. (Slide No. 12) In other studies Herbert Hudson has shown that the incidence of water-borne diseases is much lower in cities which are served by low turbidity water.

Much of the study in turbidity measurement is based on its application in the water treatment industry, the characteristics of turbidity and its control are fast becoming fields of interest for various industrial and consumer markets. Fluid clarity can be quantified in terms of turbidity, and many sources now feel that turbidity measurement will become a more universal quality-control parameter in all optical fluid studies.

OPERATOR EXPERIENCE OF FILTER CONTROL BY USE OF  
SUSPENDED SOLIDS DETERMINATION WITH MILLIPORE FILTERS

Robert E. Hansen  
Supt. of Water Purification and Pumping  
Mount Clemens, Michigan

Suppose I made the statement that your filters are not doing as good a job as you think they are doing - you would be shocked, and rightly so! And, under certain conditions, this could be quite true! And further, that even if your turbidimeters indicate you are putting out a water of zero turbidity, you still might have turbidity in your filter effluents. Another shock? Yes, and most likely this is quite true also!

It came as a rude shock to us in 1962, when we had complaints from some of our customers which indicated that activated carbon was passing our filters. Especially since the first complaint came from the mayor's wife. The dark water caused by carbon could easily be seen in toilets and bathtubs and left a greasy, black ring around the bathtub. One of our men said this must be the only water that leaves a ring around the bathtub BEFORE you take a bath!

We checked our turbidity records and all showed no turbidity. We "trouble-shoot" all our complaints and had adequate samples from the complainant's taps. We checked these on the turbidimeters and found zero turbidity, so we tried filtering a quantity through a Millipore filter and there it was - carbon - black and plain as day, or should I say "night"?

Why didn't this register on the turbidimeters? This involves the physics of the instrument design - it is in the properties of reflectance and transmission of light. Particles like carbon (for one thing) do not reflect light, apparently, and do not register. So we realized that we could not depend on turbidimeters as a guide on the quality of our filter effluents. We began in 1962 to make regular use of this method to check filtered and tapwater and to make permanent records of same by pasting the filter discs (after drying) in folders as a permanent record of our quality control work.

Since 1962, we have also used them on our Extremity Surveys which we make twice a year. When we started these surveys in 1957 we made them four times a year, but later cut back to twice a year - when the water is the warmest and when it is the coldest. This is done by sampling at the outer

reaches of the distribution systems we supply with water. They are not dead ends - dead end sample analyses and Millipore filters go in a separate folder. Extremity survey sampling is done towards the outer limits of the fringe edges of the systems - where there is still some circulation. We analyze for total and free chlorine, total ortho and metaphosphate (some reversion tends to increase through the system), turbidity, fluorine, pH, copper and iron. We also record the temperature. This tells us many things including how well our chlorine, fluorine and phosphates are holding up in the distribution mains. Any cast iron pipe corrosion is visually evident on the Millipore filters.

The Mt. Clemens plant supplies approximately 79,000 people with water - the City of Mt. Clemens and the Selfridge Field Air Force Base, plus all or portions of the Townships of Clinton, Harrison, Macomb and Chesterfield. The population has grown to this figure from approximately 21,000 when I first took this job in 1942. The plant was expanded in 1959 and a contract for supplementary water was signed with the City of Detroit in 1966. We began regular use of Detroit water in December of 1967 through an emergency line. The plant is over-loaded during the summertime demands and will be until the principal connection with Detroit is completed, which we hope will be this coming winter. Then we will stabilize at about a five million gallon per day, average day, and with maximum days about eight million gallons. Last summer our total demand was over 16 m.g.d.

The source of our water is Lake St. Clair - a relatively shallow lake between two of the Great Lakes - Huron and Erie. We are affected by the runoff from the Clinton River, the mouth of which is about four miles in an upstream direction from our intake.

I remember better times when the water was at its best during the summer and in the winter with an ice-cover over the intake. Turbidities ran less than two during those periods, and the quality was good except for the spring run-offs or heavy winds which stirred up the lake. The highest raw water turbidity was 600 for any single test. Now our record goes to 1000!

At the same rate as population increased and as we drew harder on our intake, the quality of the water seemed to lessen. We went through a period of bad phenol tastes and odours during spring run-offs between 1942 and as late as 1957 when it was finally eliminated. During the earlier years the International Joint Commission determined it was a Michigan problem and the State Water Resources Commission took it over. We helped, through an intensive public relations effort in 1949-1950 for public support of the State's efforts, to rid our water of the phenol taste and the end result was complete success.

In 1958 the quality of summertime water became seriously affected by severe bouts with a moldy-musty taste and odour. Upon concentrated investigation the cause was laid to actinomycetes - a higher bacteria - whose metabolites are very powerful in causing moldy-musty tastes and odours. The growth of the actinomycetes seemed to be tied to lower lake levels. Then when high lake levels seemed to promise relief we were assailed with similar tastes and odours that came from algae. Algae had never been a problem before but they have persisted since. So the quality of the lake water has changed and for eleven summers we have had tastes and odours from either algae or actinomycetes or both. This is background information on activated carbon use and need for Millipore filter quality control of filters.

We tried potassium permanganate which seemed to work well on certain specific taste and odour causes like aldehydes, and we used chlorine dioxide when we had phenols (and tried it on the musty-moldy also). But for all other causes we have had to rely on activated carbon. As the water quality diminished through the years we had to increase our application of granular carbon and, coupled with higher filtration rates as population increased, it was 1962 before we realized that higher dosages of carbon were penetrating the filters.

Part of the reason was in the coarser sand. The filters had Ottawa Silurian filter sand from Ottawa, Illinois, of 0.4 mm effective size and 1.35 uniformity coefficient, up to 1956. To hold us over until the plant was expanded, the City's designing engineers specified 0.65 mm effective size filter sand and re-built all filters with this coarser sand. Similarly, the 1959 filters had a coarser sand, to maintain a high rate of filtration of 3.0 million gallons per square foot per minute. (The State Health Dept. had issued a temporary permit for this rate until the final plant expansion took place. When it was evident that this was not going to come about, the rate was reduced to  $2\frac{1}{2}$  gals/sq.ft./min.)

In 1962, we searched for means of retaining the carbon on top of the filters. Our carbon application was either at the Flash Mix or midway in the first half of the settling basin, or at both points when all machines were wide open. However, the carbon did not all settle out and the water on top of the filters was usually black with carbon. In addition to standard clarification practice, we tried various coagulants and coagulant aids just ahead of the filters, to build up a mat on the filter surface to hold the carbon. The product that helped the most was "Catalyzer", a starch poly-electrolyte made by the Electric Chemical Company of Cleveland (or ECCO as it came to be known). Dosage of this product varied from about 1 to 4 ppm depending on carbon dosage and the measure of

success experienced. (Since then the Mich. Dept. of Health has set 3 ppm as the top limit of application of this material.)

All during these trials and during carbon application we measured our success or failure by the use of Millipore filters. We very early determined that 500 ml. was the best quantity of sample to run through a Millipore filter to give us the range of test results we needed. A liter would give difficulty in passing a Millipore filter for a very turbid sample. Less than 500 ml. was too little as the colour gradations of the retained material were not great enough. So we standardized on 500 ml of sample since 1962.

The coagulant aid application just ahead of the filters seemed to minimize the quantity of carbon passing the filters, but there were times when we would obtain poor results which were difficult to understand. We found one of the causes to be the presence of synthetic detergents in the raw water and this occasionally happened in the run-off season. When we could see foam building up at the fish screens just past the flash-mix, we would also see more carbon passing the filters and showing up as deposits on the Millipore filters. Since 1965, when the hard detergents were all replaced by soft detergents, we have not seen the build-up of this foam. The evidence was gone but the detergents in another form were possibly occasionally there.

Our dry carbon machine capability limited our success in handling the tastes and odours. During early run-offs with lower pumpage we could get up to 43 ppm of activated carbon application, but in summer with higher pumpage we could only apply up to a maximum of 28 ppm. I estimated needs could go actually as high as 100 or maybe even up to 150 ppm during maximum taste and odour problems. Dry feed machines were not the answer, so we would have to go to carbon slurry. We had no railroad siding so we began in 1960 to try to interest the activated carbon supplier in making an investment in truck bulk carbon delivery, in order to have carbon slurry at our plant - in an efficient and economical form. In 1962, we circularized operators of 100 water treatment plants in Michigan and two adjoining states. Results turned in encouraged the supplier to invest in truck bulk delivery and this became a reality just three years ago. On August 24, 1967, I formally requested the city to invest in carbon slurry tanks so we could apply enough carbon to handle any taste and odour we had been experiencing. This was under investigation by the City's engineering consultants. In the fall it suddenly became evident that our filters were in need of immediate re-building.

We had been keeping a record of the gravel condition through the years by the simpler method of passing a yardstick into the sand until the gravel layer stopped it, and recording the sand depth at that point. This is repeated every foot in both directions and in all filters. Convenient marker sticks are used for this purpose and a form to record all the sand depths. The gravel was not in really bad shape until the fall of 1967.

At the same time we were approached by the Calgon Company people with a new product - granular carbon for filters to remove tastes and odours as well as doing the filtering. The grains were about the size of sand -0.55 mm effective size - and were "shot full of holes", so they had surface area comparable to activated carbon.

So now we had two choices. The City Manager, unable to make up his mind, referred the problem of choice to the consulting and designing engineers Ayres, Lewis, Norris and May of Ann Arbor, Michigan. Their report of Dec. 28, 1967 selected the granular carbon over the carbon slurry tanks on an economic basis. Future plant waste disposal problems was also part of the consideration. The State Public Health Department of Mich. was reluctant to allow us to remove more than six inches of sand in order to install the granular carbon. A two-foot depth was required of the granular carbon. The Calgon Company representatives were able to prove to the satisfaction of the Mich. Department of Public Health officials that granular carbon did just as good a filtering job as sand did so they allowed us a permit with as little as 6" depth of sand underneath the carbon. We have three types of filter underdrains - the Leopold bottom, the Wheeler bottom, and Wagner Blocks with Transite laterals. So, because of this and the positions of the filter troughs (different in the 1929 and 1959 filters) and to leave room for the Palmer Filter Agitators, the sand depth varies from 6 inches to 16 inches. This sand is again the fine Ottawa Silurian filter sand as used from 1929 to 1956.

Filter reconstruction with all new gravel and sand, and two feet depth of granular carbon in all eight filters, took from January through March. By April 1st. all filters had been rebuilt - in time for our summer demands.

There were many "fines" or dust - looking like powdered activated carbon - that penetrated the filters after rebuilding. Especially immediately after. All of which were recorded on the Millipore filter discs for the permanent records. This dust persisted for several months - until summer began. The dust would show up on Millipore filters especially right after a back-wash, but no worse than if we had been applying activated carbon.

Since April 1968 we have NOT had any tastes or odours in our city water and the granular carbon does a beautiful job of filtration - as evidenced by the Millipore filter records. I have brought all of our record folders made since 1962, so you can have a look at them first hand, and please note in particular the excellent filtering record we have had since the summer of 1968! We have no powdered carbon to penetrate the filters anymore and the granular carbon is doing a great job of filtering. We had a few problems with the granular carbon, but we worked out all of them successfully. We had to rely on our own experience, trials and advice from the Calgon Company as we are in a brand new area. We are one of only four municipalities in this hemisphere that have these granular carbon filters and we are very proud of the fine water they are turning out.

We have used our Millipore filters to great advantage in quality control of our filters, and also in our investigative work on water quality - our extremity surveys, on dead ends, in trouble-shooting work both in the plant and in the system we serve.

We used a rubber cement to glue these filter discs in the permanent records, but it became evident a year ago that these were falling out as the glue dried up completely. So we tried to convert to Elmer's glue for a more lasting bond. It took awhile to educate the plant attendants to this, as the rubber glue was so much more convenient to use. We finally succeeded in this a few months ago. All the older loose Millipore filters had to be re-glued with Elmer's glue. It is much neater also, as rubber cement was sloppy and accumulated soils.

I do not know of any other plant using these Millipore filters the way we do. Ray Harwood, Purification Supervisor at Flint, Mich., came across the same phenomena as we did and about the same time - material going through filters without registering on the turbidimeters - and checking same on Millipore filters. He reported this in the course of giving a paper at the Michigan Section AWWA meeting in the fall of 1962.

I encourage all water plant personnel to try this method of quality control, especially if you must use activated carbon. Try it many times for a few good results do not reveal anything nor prove anything. Try it at the beginning of filter runs and at the end of them. Try it in all seasons of the year, and particularly when you have heavier loads on your filters - either in high rates of filtration or in heavy turbidity loads. Try it on your distribution and dead-end problems. It was the Millipore filters that were the first "tip-off" in the fall of 1967, that

our filters needed re-building. Those Millipore filters were included in my report to the City Manager and City Commission that the filters all needed reconstruction - in the Dec. 15, 1967 letter requesting bids be taken on the re-building of filters. They have proven invaluable to us in our quality water control. I think you will be very surprised if you begin to use them regularly and they can help you to do a better job than you have been doing.

Heavy deposits on some Millipore filters (like from dead-ends) can be retained on Millipore filters for permanent records by spraying with acrylic resins from an aerosol spray can. On each individual Millipore filter record we record the date, time of sampling and turbidity as run on the standard turbidimeters (which must be reported in to the State of Michigan Public Health Dept.) which is generally zero any way. On special investigations we will record more information. Our Millipore filter records are far more valuable than the official turbidity measurements reported to the State, for they present the really true conditions of particulate matter in the water.

## RECORDING AND CONTROLLING THE CHLORINE RESIDUAL

R. J. Baker  
Wallace & Tiernan

A properly designed residual control system must strike a compromise between two opposing factors. A reasonably short control loop is necessary for the system to respond to rapid changes in water quality (chlorine demand) and to prevent loss of control through excessive hunting above and below the set point.

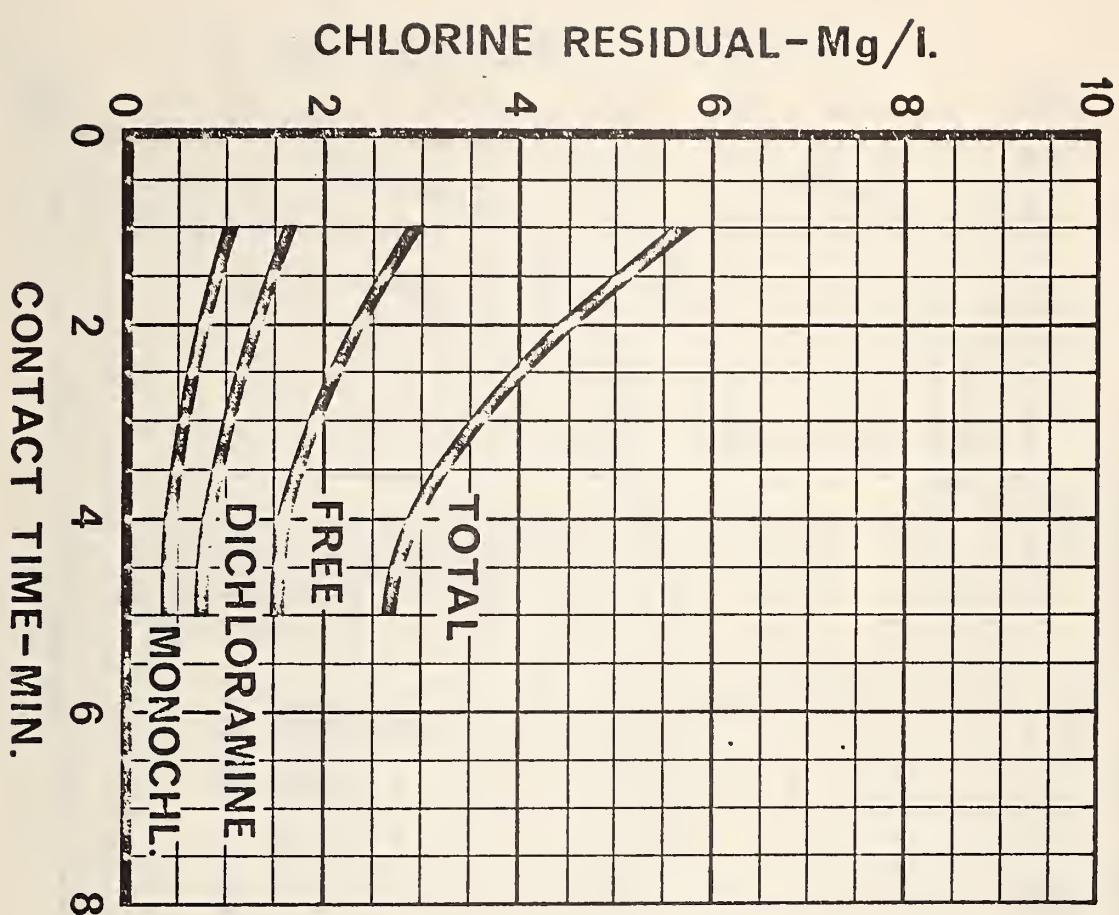
Opposed to this is the desirability of the longest possible contact time, after the chlorine is applied, so that the chemical reactions will be essentially complete.

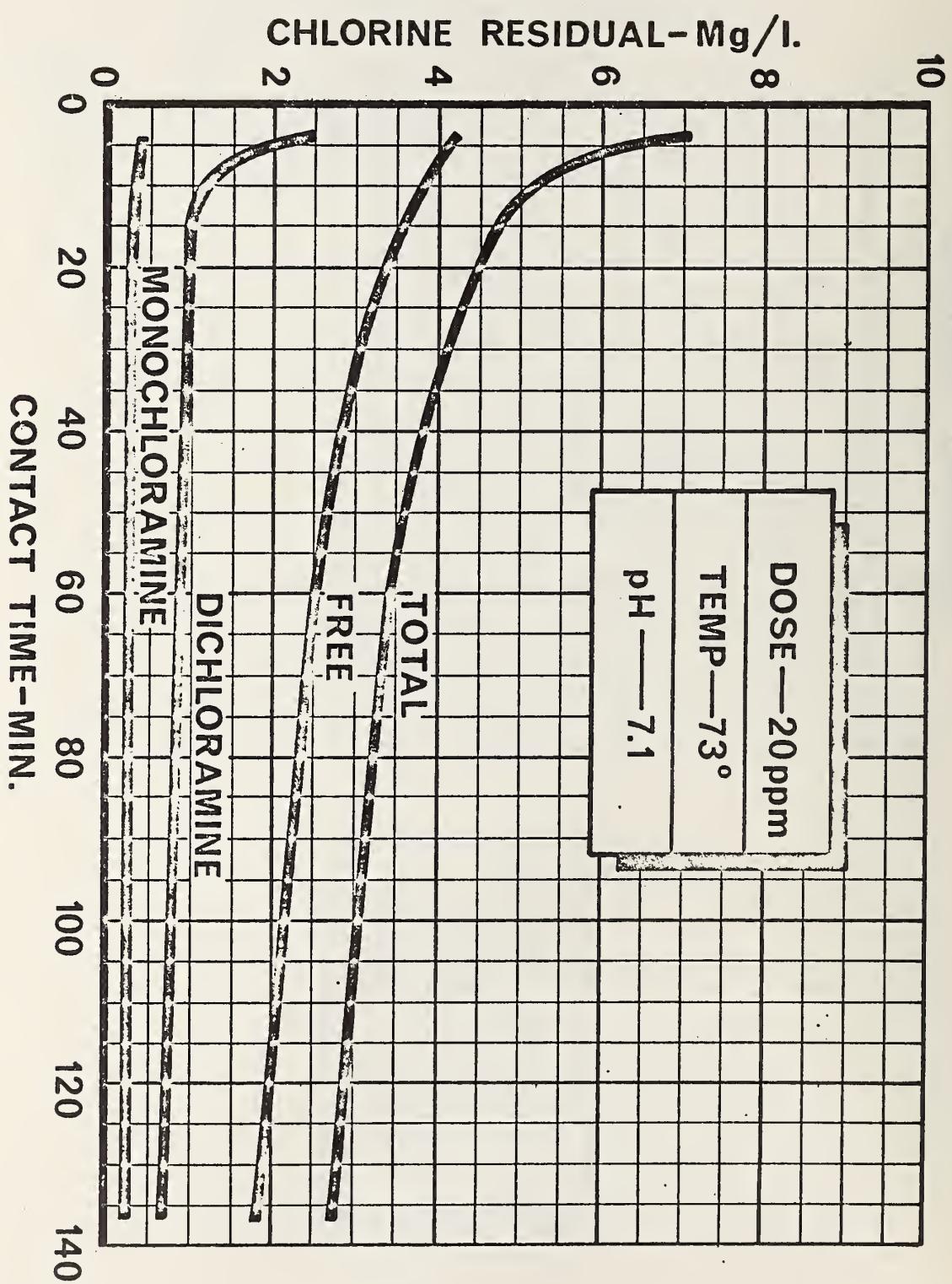
Studies of a water of reasonably poor quality (high NH<sub>3</sub> content) under breakpoint conditions indicate that these reactions are largely completed in five minutes, and that results after one hour or more can be predicted. (See Fig. 1 and 2)

A residual-controlled chlorination system must be designed around the following factors:

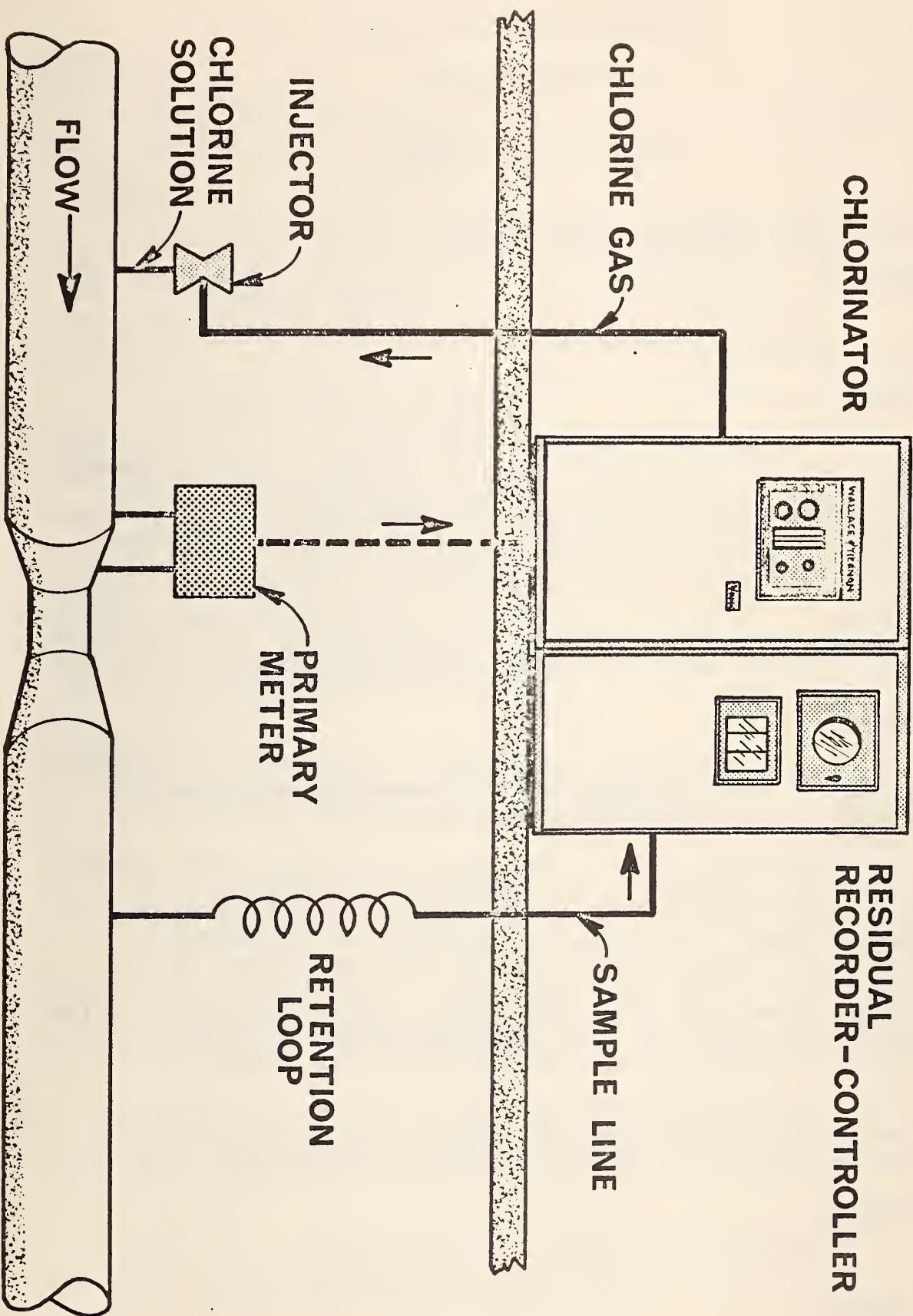
1. It must be able to respond to changes in water flow.
2. It must be able to respond to changes in chlorine demand.
3. Mixing of the chlorine with the water to be treated must be rapid and thorough.
4. The sample to the analyzer must be truly representative of the flow.
5. Chlorine contact time from the point of application of chlorine until it reaches the analyzer should be as independent as possible from variations in changes in water flow.
6. A five-minute contact time is usually satisfactory even for control of breakpoint (free residual) chlorination.

Fig. 3 is a schematic of such a system. The point of application and point of sampling should be as close as possible with adequate mixing. The remaining contact time is designed into the retention loop. The chlorinator is capable of dual control, being independently responsive to changes in water flow by a signal from a flow meter, and changes in dosage as required by the residual recorder-controller. This system has the further advantage of a chlorine feed range in excess of 100 to 1.





# COMPOUND-LOOP CHLORINATION SYSTEM



MINUTES OF AWWA SEMINAR

NOVEMBER 19, 1969.

QUESTIONS AND ANSWERS

FILTER CONTROL THROUGH ZETA POTENTIAL

Question 1

Why are you not in favour of lime addition for the purpose of adjusting alkalinity?

Answer

The subject reactions take place in less than 1/10th of a second. Lime takes too long to dissolve and consequently, coagulation and flocculation are still occurring while dissolving occurs. In addition, addition of lime increases problems to the water users. That is, it is a needless addition of hardness to the water.

Question 2

Would you briefly describe the Zeta Meter.

Answer

Our Zeta meters are compact and rugged. It requires about 15 minutes to explain the operation to an operator and to set-up and align the meter.

The secret of the success of the meter lies in its simplicity of operation. Basically, it consists of a small cell with a hole through it and electrode holders at each end. The liquid to be tested is introduced to the cell. The relative motion of the particles can be determined by reflecting a beam of light through the solution and observing the motion through an optical system on which a scale has been etched. Interpretation of the relative motion is used to define the Zeta Potential.

As mentioned previously, a very short period is required to set-up the instrument. Similarly, changing the cell for a new sample is quickly completed.

Question 3

What is the cost of the instrument?

Answer

Approximately \$3,000.

#### Question 4

How does one establish Zeta Potential by means of reflection patterns?

#### Answer

The time required for a particle to cross the reflection division lines is timed. Actually, the relative motion of the flow defines the Zeta Potential.

#### Question 5

Is measurement of Zeta Potential applicable to colour control as well as turbidity control?

#### Answer

Yes. The Zeta Potential should follow colour more closely than turbidity keeping in mind that turbidity is an optical property. The lowest particle count in all size ranges is obtained at zero Zeta Potential, and the lowest colour residual is obtained at zero Zeta Potential. A mixture of colour and turbidity may mean that one would have to sacrifice one property for the other, because of the probability of a different critical pH for each.

#### Question 6

Would you please explain how, with the aid of your meter, one determines the proper coagulant dosage?

#### Answer

- (a) obtain a starting point (a specific alum concentration and pH);
- (b) test;
- (c) alter the alum concentration in the desired direction to reduce the Zeta Potential;
- (d) test;
- (e) alter the pH to move the Zeta Potential in the desired direction;
- (f) test;
- (g) alter the alum concentration;
- (h) etc.

The trend will direct you to the optimum.

### Question 7

Is it possible that the optimum position for an operation may not be at the zero potential?

#### Answer

The ideal filter condition is to obtain breakthrough at the same time as headloss is obtained. This may not necessarily occur at zero Zeta Potential. It is conceivable that a zero Zeta Potential could produce too strong a floc.

## FILTER CONTROL THROUGH THE COAGULANT CONTROL CENTRE

### Question 1

If an operator were feeding, say, a coagulant plus one or two coagulant aids simultaneously, what would he do in the instance of a turbidity increase? Which feed rate would he change?

#### Answer

Improper flocculation is distinctly different from improper coagulation. The purpose of the system is to show improper coagulation. A bit of judgement is required. The operator must decide what to do in a specific instance.

### Question 2

Have these centres been used for colour control as well?

#### Answer

Yes. Colour can be considered analogous to turbidity. A "colourimeter" could be established. (Although to date, such equipment has not been marketed).

### Question 3

Is there a minimum size of plant at which a control centre would be economical?

#### Answer

It is difficult to evaluate the size. For control at 7 or 8 points, a complete system might cost \$16,000 to \$17,000. Smaller plants might get by with fewer test points, although flexibility is lost.

## TURBIDITY MONITORING

### Question 1

How are these units calibrated? Are there standards available?

### Answer

The units are calibrated on the basis of a Jackson turbidity meter with a standard, consistently behaving, chemical (formazine).

### Question 2

Do these units function under conditions of oil contamination?

### Answer

Usually they will not operate properly with oil contamination. This depends upon the form of oil in the water.

### Question 3

Is there a direct relationship between Jackson turbidity units and turbidity in ppm?

### Answer

It is incorrect to compare ppm with JTU. The standard measure of water turbidity is JTU and JTU is not synonymous with ppm.

### Question 4

Do you get a direct correlation of percentage errors on the two ranges of the meter? How can you determine accuracies in the very low ranges?

### Answer

There is no direct correlation in per cent error in low and high ranges. It is impossible to effectively prepare very low concentrations equivalent to, say, a turbidity of 0.2 JTU. It must be done by graphical interpolation from higher ranges.

## OPERATOR EXPERIENCE OF FILTER CONTROL BY USE OF SUSPENDED SOLIDS DETERMINATION WITH MILLIPORE FILTERS

### Question 1

When you switched from sand to carbon filters, was there much change in the turbidity?

### Answer

The turbidity decreased to zero, even with raw water turbidities in the 1000 JTU range. Granular carbon was definitely the answer and no undesirable side effects have been observed. It is necessary to backwash at higher rates but much better expansion is obtained and less water is required.

### Question 2

Have you replaced the granular carbon yet. How long do the suppliers claim the carbon will last?

### Answer

We have not yet replaced the granular carbon. There are four similar plants that I am aware of and durations of six years are expected. The supplier's warranty is for two years. We have calculated that after three years, we have broken even in comparison to sand filtration. We really do not have enough experience to forecast this aspect properly.

### Question 3

Do you wash the carbon thoroughly before placing it?

### Answer

It was supposedly thoroughly washed before shipment. There is bound to be a dust problem initially because of the way in which it is shipped.

### Question 4

In using the Millipore Filters are you operating strictly by visual observation or is the material weighed?

### Answer

Due to staff limitations, we do not weigh the filters.

Question 5

What rate is the filter operated at in terms of gpm/ft.<sup>2</sup>? What is the maximum rate?

Answer

The 1959 allowance was 3 gallons/ft.<sup>2</sup>/ minute. The standard is 2 gallons/ft.<sup>2</sup>/minute, but I believe Detroit uses rates as high as 6 to 9 gallons. The allowable rate depends on the raw water quality. In our case, the Michigan Department of Health specifies the maximum allowable limit.

Question 6

Have you any idea how this would compare with anthrafilt?

Answer

Anthrafilt will not erase tastes and odours.

RECORDING AND CONTROLLING THE CHLORINE RESIDUAL

Question 1

On the charts that you demonstrated, the dosages were similar for all cases. Was there any attempt to vary the dosages?

Answer

Yes. I have merely used a portion of our data for illustrative purposes. These examples represent minimum dosages to produce breakpoint reactions. I am sure that higher dosages would have produced smaller reaction times. It would be interesting to examine what happens during the first minute of contact. Unfortunately, the techniques now available do not allow small time interval investigations.



Date Due

ONTARIO WATER RESOURCES COMMISSION  
DIVISION OF SANITARY ENG.  
MOE/THI/ARZJ  
THE THIRD WATER WORKS SEMINAR  
ON THE TOPIC OF MONITORING AND  
CONTROLLING THE WATER TREATMENT  
PROCESS.

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